NATIONAL GEOGRAPHIC SOCIETY

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THE PHYSIOGRAPHY

OF THE

UNITED STATES

TEN MONOGRAPHS BY J. W. POWELL, N. S. SHALER, I. C. RUSSELL, BAILEY WILLIS, C. WILLARD HAYES, J. S. DILLER, W. M. DAVIS, G. K. GILBERT.

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PREFACE.

The study of the origin of earth forms has made remarkable progress during the last twenty years, so that it is scarcely exaggeration to say that a new science has been created. While those who have aided in its development are learned investigators exploring the frontiers of human knowledge, the more important results are so simple as to be appreciated not only by intelligent laymen, but even by school children. Practical experiment has shown that the explanation of the work of rain and streams in the shaping of the earth is one of the most attractive and fruitful nature studies which can be introduced into primary and secondary schools, and a movement has been organized among educators for its extensive introduction. Professor W. M. Davis of Harvard University, who is a leader in this movement, proposed about two years ago that the National Geographic Society undertake the preparation of a series of essays on geographic subjects, enlisting in the work some of the numerous specialists in its membership, and making such arrangements for publication that the essays should be accessible to the teachers of the land. This proposition was developed and discussed at a conference held in Washington in June, 1894, and a few months later the managers of the society took action, appointing an editing committee under the chairmanship of Major J. W. Powell. Arrangements for publication were made with the American Book Company, and this volume is the first product of that coöperation.

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PHYSIOGRAPHIC PROCESSES.

By J. W. Powell.

Physiography is a description of the surface features of the earth, as bodies of air, water, and land. In it is usually included an explanation of their origin, for such features are not properly understood without an explanation of the processes by which they are formed.

The earth has three moving envelopes. These are, first, the *atmosphere*, which covers it to a great depth; second, the *water*, which covers more than three fourths of its surface with sea, lake, stream, and ice field, while the whole is covered intermittently with clouds; and, third, a garment of *rock* in beds, layers, and piles.

These outer, middle, and inner garments of air, water, and rock are forever in motion. Each envelope has a system of motions of its own, yet all three act and react upon one another in such a manner, that, while their motions are independent in part, they are at the same time interdependent in part.

Within the envelopes is the great central body of the earth, which is but little known, but about which there has been much speculation. Many scientific men believe it to be solid, and deem that this is proved from certain evidence derived from the tides; other scientific men believe that the interior of the earth is in a subfluid condition, due to the pressure of the superincumbent envelope of rock. For present purposes it is unnecessary to weigh the evidence for these two hypotheses and judge between them. What we need is to understand clearly that there are three pretty well defined envelopes that are in motion, and ever interacting among themselves in such a manner, that there are sea bottoms, plains, plateaus, mountains, hills, and valleys in the rock envelope; there are seas, lakes, streams, and clouds in the aqueous envelope; and there are winds in the atmospheric envelope; and that the winds, clouds, storms, streams, lakes, seas,

valleys, hills, mountains, plateaus, plains, and sea floors are all related to one another, and always changing. That which is sea floor at one time is plain at another, plateau at still another, mountain summit at still another; and hills and valleys follow in succession, for the land seems to be always rising and falling.

Another great fact requires mention in this place. It is generally believed that the earth is surrounded by and permeated with an *ether* which extends in space through the solar system and into the region of fixed stars. By means of this ether the earth is in constant communication with the moon, the sun, every planet, and every distant orb, and through it comes to the earth a constant flow of light and heat from the fiery globes of space.

THE ATMOSPHERIC ENVELOPE.

Changes in the air come chiefly in four ways:—

First, It moves with the rest of the earth, of which it forms a part, in rotation about the central axis.

Second, Being heated at the tropics and cooled in the polar regions, the air about the equator rises, and flows poleward in both directions. In the polar regions the air, being cooled, sinks, and flows toward the equator. The great velocity of the winds in equatorial regions as they are carried eastward with the rotating earth, and the small velocity of the polar winds due to the same cause, interact with the polar-equatorial currents, so that the air flowing toward the poles is turned eastward, while the air flowing toward the equator is turned westward.

Third, The vapor of water from the surface of the sea and land is carried in the clouds by the winds, and from time to time is discharged from the air as rain. In this discharge great changes of temperature are involved, and vertical currents of air are thus set up which greatly modify the direction and velocity of the winds.

Fourth, The surface of the land affects the direction of the lower winds: for mountains change the direction of air currents; hills turn the winds through valleys; and cliffs, banks, ledges, and rocks produce eddies in the lower atmosphere.

The effect of these four processes is to make the winds seem fickle, and yet they are ever obeying law.

Above the surface of the earth the winds become more con-

stant as they are more and more governed by the great laws which change with the hours of the day and the seasons of the year.

Climatic temperature is the temperature of the air, measured in the shade so as to avoid the direct radiation of the sun. This temperature decreases from the equator to the poles. Thus there is a latitudinal change of temperature. Other things being equal, the higher the latitude the cooler the air.

The earth revolves on its axis, which gives us day and night. The air is warmer by day and cooler by night.

Then the axis of the earth, about which it revolves in its daily rotation, is inclined to the plane of the orbit of the earth in its revolution about the sun; for this reason the poles are turned alternately toward the sun, and this produces a summer and winter every year.

Temperature has still another variable, which is of great importance in the study of climate: this is altitude, or the elevation of the land above the level of the sea. In ascending through the air in a balloon, it is found to be cooler as the aërial voyager rises; so in ascending from plains to plateaus the upper regions are found to be cooler, and in climbing from valley to hill and from hill to mountain a like change of temperature is observed. The summits of many high mountains of the world are in regions of perpetual snow and ice.

Thus there is latitudinal, diurnal, seasonal, and altitudinal variability of temperature, and to all of these must be added the variability which arises with changing winds and conditions of moisture.

The diurnal and annual motions of the earth, and their relations to the movements in the air and ocean, is a subject so well taught in our schools that it need not be carefully treated here; but reference is made to it for the purpose of showing the way in which it enters into the subject of physiography.

THE AQUEOUS ENVELOPE.

The envelope of water is changeable in a variety of ways:—

First, As the moon revolves about the earth from east to west, gravity drives the water behind it, so that the tides roll their waves against the eastern shores; but as the moon proceeds, the tides roll back eastward to beat in waves against the western

shores. So with the revolving moon the tides sweep back and forth across the surface of the sea, and alternately lash the shores with their crested waves.

Second, The seas are heated under the tropics, and cooled in polar zones; so that the water of the equatorial regions, warmed and expanded, flows over the surface northward and southward toward the poles, and the waters cooled in the polar regions sink, and flow toward the equator.

The varying rotational velocity of the earth's surface at different latitudes — from the equator, where it is more than one thousand miles an hour, to the poles, where it is practically nothing — interacts on flowing waters, as on the winds, and makes those which flow toward the poles turn to the eastward against the westward-facing shores. So all surface currents drift eastward in going toward the poles. The currents thus formed are deflected by continental shores and obstructing islands, so that currents more or less clearly defined are established in the sea, modified to some slight extent by the great gulfs and the outpouring rivers from the land where the currents follow the shore.

Third, The winds drifting over the sea beat its surface into waves. When the winds are lulled, the billows go to rest, and the sea is calm and glassy; but when the storms rise, the billows rage.

Fourth, The heat of the sun and other bodies of space, aided by drying winds, evaporates the waters from the sea; and the vapor thus formed is drifted by the winds and gathered into clouds, and precipitated upon the earth, where it gathers again into rills, brooks, creeks, and rivers, to roll back into the sea.

Fifth, In high southern and northern latitudes, and at great altitudes in the temperate and torrid zones, the moisture in the atmosphere is congealed, and falls to the earth as snow, and thus mantles the earth with a robe of ice. In high altitudes and latitudes the snow accumulates in excess of the evaporation until great ice fields are formed. Under pressure, ice flows in some respects like water, but very slowly. On the summit of the mountains of tropical and temperate regions such ice fields are formed, filling the gorges, and extending over the crags and peaks. In high latitudes at the north and at the south, great ice fields accumulate on the plains and plateaus, as well as on the mountains, and glaciers of vast extent are thus formed. The ice-covered area about the poles is variable. In some regions and at

some times it extends farther toward the temperate zone, while in other regions and at other times the ice field retreats.

Waters have constant motions and variable motions. The tides are somewhat constant, and yet somewhat variable; the waves have elements of constancy and elements of variability; the clouds, in so far as they depend on evaporation, have elements of constancy and elements of variability, derived from the exposure of surfaces to the sun and constant and variable winds. After the water has been evaporated in the heavens, it drifts with the winds, which are in part constant and in part variable. The waters, like the winds, are modified by the rocky envelope; for, though largely under the sea, it is in many regions but little below the surface of the sea, and influences its currents and the evaporation of its waters. Other portions of the rock envelope lie above the sea-level, as plains, plateaus, mountains, and hills, and by their geographical distribution break the course of the winds, and greatly influence both evaporation and precipitation. Lands gather the waters which fall from the clouds into streams, which are governed by the land slopes until they empty into the sea. So the winds influence the waters, and the waters influence the winds, and the rocks influence the waters and the winds, and the winds and waters influence the rocks. All — rock, water, and air — are ever in motion, governed in part by constants and in part by variables.

Rainfall. — The evaporation of water from the surface of the earth is very irregular. In general there is more evaporation from water surfaces than from land surfaces, more in dry weather than in wet weather, more in hot weather than in cold weather, and more in high winds than in calms. As the water is evaporated from the sea and the land, it is carried away in the air to form clouds, which are in part gathered by diverse winds, and in part directed by diverse lands into diverse regions. It is in this manner that the water is precipitated from the clouds irregularly over the surface of the earth, some regions receiving more, other regions less, while in every region the rain is intermittent. A great rainstorm may come at one time, and a great drought at another: now the lands are flooded, and then the lands are parched. There are regions of the earth where the annual rainfall is more than six hundred inches, and there are other regions where the annual rainfall is not more than three inches. Thus in passing from land to land great irregularity of rainfall is discovered. But

within the same land there is variability from time to time. Maximum storms may give more than twenty inches of rain, while that given by minimum storms cannot even be measured in inches, the unit is too large; a mere dampening of the surface results therefrom.

Run-off.—The land is everywhere traversed by a network of streams—as rivers, creeks, and brooks—which meander from the highlands down the valleys, little and great, uniting again and again, until as rivers they roll into the sea.

In lands of great rainfall the streams are many and large, whereas in lands of small rainfall the streams are fewer and smaller; but the decrease in the number and size of the streams is much greater than the decrease in precipitation. Stream aridity is greater than atmospheric aridity. In arid climates, where the rate of precipitation is less, the rate of evaporation is greater; so that aridity promotes evaporation, and thus still more diminishes the size and number of the streams. Under average conditions, where the mean annual rainfall is forty inches, about twenty inches of the precipitation is evaporated from the surface of the land, and twenty inches is gathered into streams to be carried away to lakes and seas. If the mean rainfall is more than this, the mean run-off by streams is more than half the run-off; but if the mean rainfall is less, the mean run-off is less than half the rainfall. Where the rainfall is but ten inches annually, permanent streams are not formed. When they are found in such regions, they have their sources in other regions where the rainfall is greater. Other conditions being equal, the rainfall is greater about mountains, as mountains furnish conditions for increased precipitation. There are regions in the United States, as elsewhere in the world, where the rainfall is less than twenty inches, and where streams of water are gathered by mountains to roll down in deep rocky gorges. Such streams usually diminish in size as they proceed, until their waters are evaporated. Often they end in marshes and swampy lakes, where the sands are deposited by the dying rivers and creeks. Locally these are often called *sinks;* and many people who do not understand the laws of evaporation, precipitation, and run-off, suppose that the streams actually sink beneath the surface of the earth, to flow in underground channels. There is a popular belief that there are many underground rivers of this character in the dry regions of the

far West. In all regions there are underground waters, as the loose soils, sands, and gravels retain much water; and the sands at the mouth of a vanishing stream also contain more or less subterranean water of this character, which is more slowly evaporated into the heavens; but these so-called *lost rivers*, carrying waters from mountain streams of arid regions, do not exist, and the popular error in this respect has no foundation in fact. Yet there are lost rivers of another character, where streams disappear from the surface and run in underground channels, to reappear below.

On the plains and in the valleys of regions where the annual rainfall is less than ten inches, or even less than three inches, intermittent streams are sometimes formed. This little rain often comes in great storms, and storm-water streams are thus produced, whose waters flow for a time as creeks of mud, but are soon lost by evaporation. The mud which is thus swept down from the hills and higher ridges is deposited in the valleys below; and gradually, through years and centuries, the valleys and lowlands are covered to great depths by such deposits.

In regions of country where the rainfall is twenty inches or more, permanent streams may be formed which ultimately discharge into the sea; and the sands which are washed down by flood waters are deposited in part along the course of such streams, to be carried along again when other rains come, until finally they are swept out to the ocean, where they are deposited as deltas or carried along the seashore, to be built up in banks against the land or to be formed into fringing islands.

Floods.—Stream channels are the aqueducts by which the water not evaporated runs off. The streams cut their own channels. Where there is more water to be carried, the channel is made deeper or wider (one or both), and for this purpose there is more water to do the work. But the channels will not hold all the water of great rainstorms: hence floods come, for a flood is the flow of a stream over the banks of its channel. If a stream cuts its own channel, and if the greater the amount of water the greater the size of the channel, other things being equal, why is it that floods come? This question must be answered by explaining the manner in which stream channels are choked. There are many minor ways by which they are obstructed, but most of these may be neglected, as they are of small importance; but the two principal methods require attention.

By the first method, a small stream chokes a larger one; and by the second method, a stream chokes itself. Let us understand the first one.

Consider a stream without tributaries. Suppose that all the water carried by it is derived from one source, some mammoth spring with a constant supply, and that no water is added to its volume on its way to the sea. Under such circumstances, the stream cuts its own channel from source to outlet large enough to carry the volume of water, and it never overflows its bank. Now suppose another stream is turned into it, and that this tributary drains a region of country where there are intermittent rains. When the rains come, the new stream has a large volume of water loaded with mud washed from the hills and valleys, where the rains are caught which supply its volume. When the muddy stream enters the river, the sands and gravels are in part deposited below the junction. This forms a dam or obstruction, and tends to cause a flood in the main stream above the junction. Let other streams be turned into the main river; and wherever such a lateral stream comes in, a dam is constructed below the junction. Now, the river has a series of dams constructed along its course, each one of which tends to cause the river to overflow its banks. The dams constructed in this manner are washed out and built again, and washed out and built again, from time to time. Sometimes a series of these dams has been constructed just before some great rainfall, so that the stream is in no condition to carry the greater supply; and a flood results. It is in this manner that large streams are choked by smaller ones, and that floods arise therefrom.

Now, it must be understood how streams choke themselves. When the waters are low in any stream, they are clear. When the waters are high, they are muddy, for the rains which cause the increase of volume wash the surface soil into the streams. Rain thus makes the river muddy. The mud brought into the stream, being heavier than the water, sinks to the bottom. Where the waters are swift, but little mud falls; where the waters are quiet, much mud falls. The waters are swifter around the outside of a bend, and slower on the inside of it. From this slower water the mud is deposited, so the bank of the inner curve grows. As the bank grows, the water is pushed over against the other bank on the outer side of the curve, where its flow is increased in velocity so as to cut the bank, and load more material upon the

stream. The new load is in part thrown down again at the next bend on the opposite side, where the water is comparatively still. The first curve increases itself by building up on the inside, and cutting down on the outside. In the same manner the second curve is increased in the opposite direction by building up on one side, and cutting down on the other. So it is that rivers not only cut their own channels, but change their own courses from time to time. In this change the stream is constantly depositing new obstructions, forming dams, which are known as *bars;* so that, when some great rainstorm comes after such obstructions have been built, the water cannot be carried away by the channel, and it overflows its banks, and there is a great flood.

So one stream obstructs another, and a stream obstructs itself. All floods are ultimately caused by obstruction, and obstructions are chiefly caused by one or both of the methods described.

Thus far we have considered the regimen of streams in a state of nature. When man comes with the arts of civilization to change the surface of the earth, additional disturbing factors enter into the problem. Man plows the fields, and the side streams carry additional amounts of detritus, and the obstructing dams are multiplied and enlarged; he changes the courses of the smaller streams, and thus introduces disturbing elements into the larger. For the purpose of obtaining water powers, he builds dams, and again changes and introduces new elements into the regimen. Many of the things that man does upon the surface of the earth have an influence upon the run-off, and generally increase the violence of floods; but in lands where irrigation is practiced the waters are taken away from their natural channels and spread over the soils, to be reëvaporated into the heavens; and thus the streams are made smaller, and the floods are diminished or entirely prevented.

THE ROCK ENVELOPE.

The crust of the earth is changeable in a variety of ways:—

First, It rises and sinks very slowly, so that usually the changes cannot be perceived, except by comparing some level of land with the level of the sea at long intervals of time; as the hour hand of the clock is not seen to move, but known to move only by intervals of change from hour to hour. But there may be a time when this change is at once apparent; that is, when a

fissure is formed in the stony crust, on one side of which the land drops, or on the other is uplifted, or perhaps the one is downthrown and the other uplifted at the same time. The tremor formed from such a movement may be felt as an *earthquake* over thousands of square miles.

Second, When such rents are formed in the crust of the earth, molten matter is often ejected which pours out in great streams. In this manner floods of lava are spread over the surface, which, on cooling, become great beds of rock.

Third, When the rains come, and the storms beat upon the mountains and hills, their sands are washed into the streams, and by them are carried away. The materials brought down by the streams from valleys, hills, plains, plateaus, and mountains, are discharged as sands and clays into the lakes and seas, where they sink. In this manner, by rains and rivers, the lands are carried away, and new lands are formed along the shores of lakes and seas.

Seas have their tides and waves, and the lakes their waves, which beat against the shores, and undermine the banks and cliffs, and spread bowlders, gravels, sands, and clays along the margin of the waters; and all these materials are gradually carried out by the undertow to a distance from the land. At the same time the materials brought down with the streams are carried by currents, and, as they sink, they are commingled with the detritus formed by waves. In this manner lakes are slowly filled, and the seas are ever accumulating new materials upon their shores and on their bottoms.

So there are three methods by which the rocks change their positions. The first is by *displacement*, when some portion of the crust is upheaved or dropped down; the second is by *volcanic action*, when rocks are poured from the interior of the earth as lava, or hurled out by explosions as cinders and dust; and the third is by *transportation*, when rock materials are carried from one place to another by streams, waves, and winds.

The three methods of change in the stony crust have interesting relations to one another. As the land is upheaved, it is more exposed to rains and rivers; and the higher it is carried, the more rapidly is it worn down or degraded by these aqueous agencies. By this process of degradation the crust or rock envelope is weakened more and more, and still rises to be attacked by the waters. Thus more fissures are formed, more earthquakes occur, and

through the fissures come more and more bodies of lava, cinders, and ashes. The process of degradation by water seems thus to facilitate the process of upheaval and the process of eruption. But a time comes when such upheaval and degradation are checked, for reasons not fully known to the geologist; and slowly through the years, and still more slowly through the centuries, and very slowly through centuries of centuries, the upheaval is brought to an end, and the mountains and hills are then ever more slowly degraded until they are brought to the level of the sea.

As the land is upheaved, the sea margin receiving the detritus is thus loaded, and this load presses it down more and more, until at last the process of sinking ceases slowly with the slower upheaval of the land.

Why this process of sinking ceases, like the process of upheaval, is not clearly known; but the fact that such changes do cease is well known.

It was shown above how rising areas of land become rising areas of volcanic activity; it should also be stated that the sinking areas on the margin of the sea, where the sands are deposited, sometimes break as they go down, and fissures are formed through which lava, scoria, and ashes pour forth: so that there are land areas of volcanic activity and ocean areas of volcanic activity.

Then, again, lands which have ceased to rise, and have been degraded to the level of the sea, often become areas of depression, and go down below the level of the sea; while old sea bottoms that have ceased to sink appear slowly above the surface of the water and become dry-land areas, and in turn are elevated into plains, plateaus, and mountains, where fissures are formed, and volcanoes are built, and rains and rivers carve out valleys and leave hills and mountains. So land areas become sea areas, and sea areas become land areas, until the processes are once more reversed.

Kinds of Rock.—It has already been seen how fissures are formed in the rock envelope, and how vents are produced which become chimneys, through which molten matter is poured out upon the surface, and piled up from time to time by many floods, until volcanic mountains are produced whose chimneys open to the sky in great funnel-shaped craters. Thus a volcanic mountain is composed of many sheets of lava that have been poured out from time to time through its history. Some volcanoes are still active, but many have ceased to emit their floods of fire, and dead

volcanoes in vast numbers are scattered over various portions of the globe.

Volcanoes do not always emit floods of molten rock: they sometimes explode, and throw dust, ashes, and scoria high into the air, which, falling to the earth, are piled up in formations of *tuff*. The very fine dust is sometimes drifted by the winds over great regions of country for hundreds or even thousands of miles; but the coarser materials soon fall, and by a long succession of such explosions mountains of ashes and cinders may be formed. In volcanic regions, cones of such cinders are common. Sometimes they attain great size, so as to be several hundred feet high; and they are usually characterized by distinct craters.

Rocks formed of lava and accumulations of ashes and scoria are called *igneous* rocks.

Many rocks are soluble, so that the rains, streams, and waves dissolve them. This soluble material is chiefly carried into the sea, where it is deposited by various agencies. The saltness of the sea is caused by salt which is washed out of the land and carried into it. The suspended material is carried into lakes and into the sea. Thus the waters grind down the lands, and bear them away to be deposited under the lake and ocean. The materials are arranged in layers, thin in some places, thick in others. Very fine materials make thin layers, coarser materials make thicker layers, all of which are called *strata*. Now, these strata differ in constitution in many ways, because they come from different streams, which collect sands and clays from different regions of country, and because the waves that tear down the shores find different materials in different regions. Then all this material brought down to the mouths of rivers and into the surf is assorted: the coarser material soon drops, the finer material is carried farther, and the rock material held in solution is spread all over the sea. The dissolved materials thus spread far and wide form *limestone* chiefly, the very fine materials form *clay*, coarser materials form *sandstone*, and very coarse materials of gravels and bowlders form *conglomerate*.

Many animals live in the lakes and seas; and when they die, their bones are deposited in the forming strata. Many plants live on the shores and in the waters; and their leaves and stems sink into the mud, to leave their impressions, and sometimes their tissues, in the forming rocks. Plants and animals live on the land, whose hard parts are washed down by the streams, to be

buried in the waters, and leave their remains in the rocks. Even the bones of the birds of the air are buried in this manner. All such fragments of life entombed in the rocks are known as *fossils.* Above the marshes and shallow waters of lake and sea there is a rank growth of vegetation, which falls after maturing from year to year, and is overwhelmed by the waters. As the years go by, generation after generation of plants live, die, and sink below the waters, until great accumulations of such vegetable matter are formed, constituting *peat.* When afterward this peat is buried by sands and clays and gravels, it is slowly transformed into *coal*, and thus originate the coal beds found in the rocks. The leaves in these rocks afterward tell the story of the life which existed at the time the rocks were formed.

All of these beds of limestone, clay, sandstone, and conglomerate, are laid down in nearly horizontal strata when first deposited, or they incline very gently away from the shores. As strata are accumulated in the bodies of water in the manner above described, one stratum is piled on another until a number are formed, so that they accumulate in tens, hundreds, and thousands of feet. In some places they have accumulated to a thickness of more than fifty thousand feet, but such great accumulations are rare. Accumulations of ten or twenty thousand feet are quite common. As the strata pile up in this manner, the lower members are hardened or indurated.

We have thus found two kinds of rocks, — *igneous* rocks, which have been poured from the interior of the earth or blown out by explosive forces; and *sedimentary* rocks, which have been deposited in lakes and seas. A third class must be recognized, which is very abundant over the surface of the earth, and out of which the soils are made. The hard rocks below are disintegrated by atmospheric agencies, broken up by heating and cooling, dissolved to some extent by the waters, and disintegrated and changed in various ways by chemical agencies. This disintegrated material is washed down by the rains, and gathered by the rills, brooks, creeks, and rivers. Much more is washed down by the rills than is carried by the brooks, much more is carried by the brooks than is carried by the creeks, and much more by the creeks than by the rivers. So the disintegrated rocks are strewn from higher to lower lands, and piled up in this manner as bowlders and angular fragments, and as sands and clays, all commingled in many ways; so that the

lowlands have a great overplacement of these rock materials, which are not consolidated like the rocks deposited under the waters, but lie on the surface of the land as comparatively loose material. The larger streams, as creeks and rivers, have low valleys called *plains*. These streams have their channels more than filled by great rains, and the floods stretch over the adjacent lands. Wherever these floods reach, a plain is formed, known as a *flood plain*, which is built up here and there, and broken down again here and there; so that the overplaced materials brought down by the floods, and deposited outside of the channel, are constantly changing from point to point.

The sands that are formed by the disintegration of the rocks over the surface of the land, and by the beating of the waves against the shore, are drifted by the winds. When the tides of the sea ebb, great stretches of naked sand are left bare; and the winds drift the sands alongshore out to sea, and far back over the land, sometimes in great hills and ridges. The sands of the dry land of arid regions are drifted in this manner, and are often piled into hills and ridges, which slowly travel before prevailing winds. Such moving hills are known as *dunes*.

Ice is accumulated on high mountains and in high latitudes, and it moves down the slopes and along the gorges and valleys, plowing its way over rocks, and carrying into its body sands and bowlders. Thus loaded, it becomes an agency of corrasion, and excavates the valleys and polishes the hillsides, until it reaches a region so low that the ice melts, and the detritus which it carries is thrown down in irregular ridges and piles, forming *moraines*.

All of these materials may be called *mantle* rocks or superficial deposits. They are still called rocks, though rarely consolidated into hard beds. They are the rocks distributed by gradation over the land as distinguished from the sedimentary rocks that are deposited on the bottoms of seas and lakes. Thus there are two great classes of rocks due to gradation,— sedimentary and mantle rocks.

Plants grow on the mantle, which is scattered over all the land; and as they grow they die and decay and stain it black at the surface, or they are burned and their ashes discolor the rocks. This stained mantle rock is called *soil*.

And still a fourth class of rocks must be recognized. We have seen how rocks are upheaved and thrown down by causes not yet fully understood. In this manner great regions are uplifted above

the sea-level, and other regions are displaced, so that the sea flows over them. Then we have seen how the interior rocks are poured out as molten lava. By boring into the rocks, and by deep mining, it is found that the temperature of the rock crust increases from the surface downward at about the rate of 1° Fahrenheit to every fifty or seventy-five feet, as this increase of temperature is somewhat variable. Now, when rocks are deeply buried, they are subject to great pressure from the overlying strata, and they are greatly heated at depths of many thousand feet. They are also broken, flexed, contorted, and twisted as the land goes up and down; and by all these processes sedimentary rocks and igneous rocks alike are changed in both chemical and crystalline structure. The grains of sedimentary rocks are obscured, or often entirely changed into crystals; and the volcanic rocks which have one crystalline form when they cool, have another crystalline form after they have been changed by this method. All such rocks are known as *metamorphic*.

We must therefore recognize four great classes of rocks,—*volcanic* or *igneous* rocks, *sedimentary* or *clastic* rocks, *mantle* or *superficial* rocks, and *metamorphic* or *changed* rocks.

Structure of the Rock Envelope.—The upheaval and subsidence of the rock envelope is very irregular in time, in place, and in manner. Some regions of country have been subject through long geological ages to alternate upheaval and subsidence on a great scale, so that the total upheaval may be many thousands of feet, while the movements of subsidence may be many thousands of feet. There are other regions where such movements are better measured by hundreds of feet, and still others by scores of feet.

All of these movements are very slow, occurring through thousands of years. In some regions the process is gradual, so that the rocks are flexed; in other regions the process is intermittent, the rocks seeming gradually through long centuries to accumulate a strain, until at last they yield by rupture, and rise or fall along the rupture planes; then the strata of one side lie higher than those of the other. Displacements of this kind are known as *faults*. Thus there is displacement by flexure, and displacement by faulting. Faulting displacement seems always to cause earthquakes. Displacement by faulting seems to be more common than displacement by flexing, at least so far as the world has been studied by geologists. In great displacement by faulting and flexing, regions

of rock are separated into blocks which greatly vary in size and shape from district to district. As the beds are laid down by the water, or poured out by eruption from the interior, they are formed in layers—some very thin, like leaves of paper; others thicker—until some are great beds tens of feet in thickness. The beds thus laid down are broken by displacement into small blocks by transverse fractures, and are said to be jointed. There are great regions where such joints are abundant, with rocks broken into blocks only a few inches square, while elsewhere they may be in large blocks many yards square. So far as it is known, the entire rock envelope is broken into small blocks in this manner.

It has been shown that most rocks are originally formed as horizontal beds; but by displacement through upheaval and subsidence, when the rocks are faulted or flexed, these horizontal beds are tilted in great regional blocks hundreds or thousands of square miles in extent, so that in many regions we find the beds of rock inclined, and they are said to *dip* in the direction in which they are turned down. In many places the blocks are gently inclined in this manner; but in many others the inclination is great, and the rocks are found to be dipping at an angle of more than 45°; while in many other cases the strata of the blocks stand on their edges, and the dip is vertical; and yet more, in rarer cases the blocks are overturned in such a manner, that the first-formed rocks lie on top, that is, the blocks have been turned more than 90°.

A region of country composed of blocks dipping in various directions, and at different angles, may be washed down to the

Diagram of Unconformable Strata.

level of the sea, and then may slowly sink beneath the sea, and become a region of sedimentation, where rocks are once more accumulated. These new rocks are laid down in beds which are

practically horizontal, upon a floor of beds which are dipping in various directions and at various angles. In this manner the newly formed beds will not conform with the earlier strata: that is what the geologist calls *unconformity.*

Unconformity as seen in Nature.

To understand unconformity, put a dozen or twenty thin books on your table side by side, with the backs uppermost; then place other books on the top of these, the top books with their flat sides next to the edges or backs of the first series; consider the books on edge as a series of rocks dipping at an angle of 90°, and the books on top as a series of rocks lying horizontal on the upturned edges of the lower rocks. You will then understand what the geologist means when he says that he has discovered two series of rocks, one of which is unconformable to the other. It is not necessary that the first books should stand on edge (they may incline at any angle); but if the upper rocks have one inclination, and the lower rocks another, there is said to be an unconformity. It will be seen that such an unconformity has great significance in geologic history. The rocks below were formed at one time, and the rocks above at another and later time; but these times were separated by a dry-land period of upheaval and degradation which may have been very long.

Ores.—Now, the rocks, as they are laid down by water and poured out from the interior of the earth, contain iron and many other metals. As the waters percolate down the fissures, they dissolve the metals and other substances, and redeposit them in

the fissures as ores. Sometimes these fissures come to be very wide,—many inches or even many feet across,—but as they open, they are filled with ores by the percolating waters. Usually the fissures do not open completely by one movement, but open gradually from time to time; and when they thus open, they are displaced, that is, there is a vertical movement along the plane of fracture. There are thus two irregular walls; and as the movement goes on, the projections in these walls hold them apart, and the width of the fissures increases with the depth of the displacement. With every change occurring in this manner the fissure increases its width, and new deposits of ore are formed to fill the vacant spaces. Thus the ores often have a lamellar or leaf structure corresponding more or less with the walls of the fissure.

Such fissures and displacements occur more abundantly in regions of volcanic activity, where the waters are heated by the hot rocks, and their chemical activity increased by the higher temperature. This action of hot waters is known as *solfataric action*, and solfataric waters are quite common in volcanic regions.

Many of the rocks, especially limestones, are highly soluble, and such may be placed between beds of insoluble rocks. Under these circumstances, where conditions are favorable, the soluble rocks will be carried away by percolating solvent waters; and as fast as they are removed, they may be replaced by various ores. Such ore beds are common, and often of great value by reason of the great quantities of ores derived from them.

Again, ore deposits are often found in unconformities. Iron is often deposited as a bog ore in unconformities. Such ores may ultimately be covered by sedimentary rocks. Again, in such unconformities percolating waters carry away the soluble materials, and leave behind the ores of metals; so that deposits of ores are common in unconformities. As the subject of ore deposits is one of great magnitude, it is not necessary that it should receive full treatment in this place; but what has been said may be summed up in the statement that ores are found in great abundance in veins formed in fissures, that they are formed in beds where they have replaced soluble rocks, and that they are discovered in great unconformities.

Age of Rocks.—From the previous explanations of the region it will be clear to the student that rocks may be of different ages,—that some were formed a very long time ago, some but lately, and others are forming now. One of the great subjects

of investigation that geologists undertake is that of determining the age of the rocks. This research has been carried on in many lands by many men, so that much is known about the age of rocks. The oldest rocks are known to be many millions of years old, but how many millions cannot yet be decided. From the formation of the oldest rocks to the present, the time is very long. This time has been divided by geologists into periods, and the periods again subdivided; but for the present purpose it is only necessary to consider the grand periods into which geologic time is divided.

The oldest rocks known are called *Archean.* In them no fossils are found. The period of their deposition is called the *Archean* period.

The next period in succession is called *Algonkian.* In the rocks formed during this age no well-defined fossil forms have been found, and yet there are evidences that life existed.

Following the Algonkian period is the *Cambrian*, in which fossils are found with well-defined forms; but they all prove to be remains of animals of very simple and low structure.

Then follows the *Silurian* period. The rocks formed in Silurian time contain many more kinds of fossils than the rocks of Cambrian time; and their remains show that these animals were some of them of low structure, as in Cambrian time, but that others were of much higher forms.

Then follows the *Devonian* period, with a still greater number of kinds, and among them still higher forms.

Then follows the *Carboniferous* period, with evidences of plant and animal life still more varied, with forms still more highly developed.

Then succeeds the *Juratrias* period, with life forms still more highly developed.

Then follows the *Cretaceous* period, with more highly evolved life.

Then follows the *Eocene* period, with yet more highly evolved life.

Then the *Neocene* period, with fossil life more varied and more developed than ever before.

Finally we reach the *Pleistocene* period, which includes the present time. In this period the mantle rocks have been formed, while lake and ocean deposits have been made during the same time.

Thus we have the following table of periods, the last period at the top of the column:—

Pleistocene,
Neocene,
Eocene,
Cretaceous,
Juratrias,
Carboniferous,
Devonian,
Silurian,
Cambrian,
Algonkian,
Archean.

From Land to Sea, and Sea to Land.—Displacement by faulting and flexing plays a very important part in determining the physical characteristics of the land. If there were no upheaval, the rains and streams would degrade all the lands to the level of the sea, and all islands and continents would become vast marshes. But for displacement, there would be no volcanic or explosive eruption: so even the volcanic mountains would disappear. By displacement deep basins are formed in the rock envelope which holds the seas and great lakes, while at the same time dry lands are formed. But these dry lands are broken with faults into great blocks hundreds and thousands of square miles in extent, and are tilted in various directions; other regions are flexed or bent into great wrinkles; and still other regions are in part faulted, and in part flexed. All dry lands are brought above the level of the sea by displacement and igneous action; and as soon as they become dry lands, the rains fall upon them, and carry them away. It is thus that the lands are primarily due to upheaval and igneous action. Then their surfaces are modeled by rains and streams, which are the great sculptors, carving valleys, and embossing the hills and mountains.

The altitude of the region of country above the level of the sea is the difference between the amount of upheaval and the amount of degradation by the waters. The upheaval may have been hundreds or thousands of feet, while the degradation is always less if dry land remains. The upheaval is always an irregular warping, with flexures and faults on a grand scale; the degradation is always an irregular carving by rains, rills,

brooks, creeks, and rivers, aided by the beating of the waves against the shores. Where the rivers run, the degradation is rapid, for the great streams carve deep and wide channels; and these channels are narrower and more shallow where the tributary streams come down, the channels becoming less and less as the streams divide again and again, until they disappear in hillside rills. The upheaval of the land by displacement, and the building of the land by volcanic activity, are the methods by which the lands are brought above the level of the sea; and the carving of these dry lands by water is the method by which physiographic features are produced.

Man is enabled to study rocks as they are exhibited in stream banks, in the quarries of hillsides, in the faces of cliffs, in wells and in deep mines. In this manner he is enabled to see something more than the alluvial rocks at the surface. The deepest borings and mines are rarely more than a few hundred feet, though there is an occasional mine or boring which reaches down for a few thousand feet. Then we can study rocks which come from below through volcanic vents. But the geologist may study rocks that have at one time been very deep in the crust, and have since been upheaved, and the overlying rocks carried away by water; so that it is not uncommon for the geologist to see rocks which he knows have been buried in former times to a depth of thousands of feet, and he is sometimes able to examine rocks which he knows were originally deposited from forty to sixty thousand feet below their present altitude. It is by all these conditions that the structure of the rock envelope is revealed.

In a great mountain range the crust may have been wrinkled in one great flexure extending along a line hundreds of miles in length, the flexure spreading from the central line of upheaval for tens of miles. This great plain may have been uplifted in its central portion forty thousand feet or more, while the rains may have carried away from the crest perhaps thirty thousand feet or more of the rocks. So, in passing from the foot of the mountain up toward its crest, the geologist walks over the upturned edges of the strata, and studies them in succession, and measures their thickness, and collects from them the fossils which they contain, from bed to bed, as he goes up the mountain geographically, but finds rocks that contain forms of lower life. As he changes his view from the later-formed strata in the valleys to the earlier-

formed strata at the mountain summit, he reviews the history of the plants and animals that succeeded from a primeval life to the life of the present time.

It is thus that the geologist is enabled to review in one day's walk a panorama of the history of millions of years. As he walks, he may pass over beds of ancient shells, and find the bones of ancient animals, and discover the site of ancient coral reefs, and tread on the rocks of ancient shores, and find the plants of ancient forests, and at the same time gaze on canyons carved by mighty rivers, overlook valleys carved by glaciers, and watch the clouds play among the cirques and pinnacles of towering mountains.

INTERPENETRATION OF THE ENVELOPES.

The envelopes of air, water, and rock are so distinct that they can be clearly distinguished; and yet, when they are carefully studied, it is discovered that every one encroaches upon the territory of the others, not only by interaction, but also by interpenetration. It has already been shown that the water penetrates deep into the rock. Every spring that falls from a hillside gives proof that the rocks above its level hold water, which they yield slowly as a perennial supply; and the innumerable hills of the continents and islands have their innumerable springs. Every well proves that there is water below; every artesian fountain shows the existence of underground waters; and every boring in the crust of the earth, and every excavation in underground mining, discovers the presence of water.

Wherever water flows, air flows with it, and all natural waters are permeated with air.

The aqueous envelope is everywhere permeated with rock, which it holds in solution or suspension, and there is no natural water absolutely pure. The sea is full of salt. Salt lakes are more than full of salt, and so they must throw it upon the bottom; and the waters hold lime and many other substances. Not a drop of pure water can be found in the sea; not a drop can be found in a lake; not a drop of pure water can be found in any river, creek, brook, or spring; and not a drop of pure water can be found underground: it is all mixed to some degree with rock.

All natural waters are aërated. No drop of water unmixed with rock and air can be found, except by the process of artificial purification.

But surely there is pure air? Nay, not so. There is no natural air unmixed with rock and water. All the air which circulates above the land and sea, within the ken of man, and all the air which circulates underground, is mixed with rock and water.

Pure air is invisible: it will not reflect light; it is transparent, but will not convey light. Light is conveyed through the atmosphere by ether, and is reflected and refracted by rock and water; and it seems to be largely affected in this manner by rock. If the ambient air of the earth were pure, there would be no color in the sky, no rainbow in the heavens, no gray, no purple, no crimson, no gold, in the clouds. All these are due largely to the dust in the air. The purple cloud is painted with dust, and the sapphire sky is adamant on wings.

Land plants live on underground waters: were there no subterranean circulation of water, there would be no land plants. Fishes live on under-water air: were there no circulation of subaqueous air, there would be no fishes in the sea. The clouds are formed by particles of dust in the air, which gather the vapor: were there no dust in the air, there would be no clouds; were there no clouds, there would be no rain.

VULCANISM, DIASTROPHISM, AND GRADATION.

From what has hitherto been said, it will be plain to the reader that there are two grand physiographic changes by which the forms or features of the land surfaces of the earth are produced,—one by which the land goes up and down, that is, by vertical change; and the other by which the land is transported from one district to another, that is, by horizontal change.

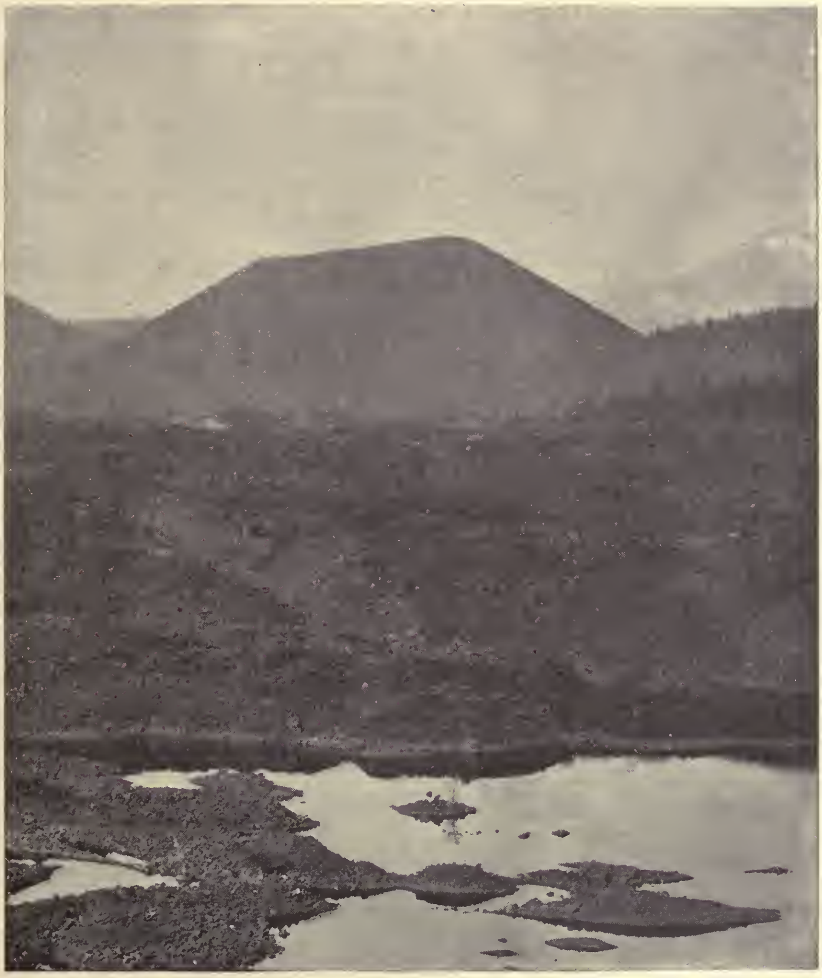
The vertical changes are produced by two processes. By one, materials from the interior of the earth are brought up to its surface. This may be called *vulcanism*, and we have volcanic processes. By the other, regions sink, and regions rise, and the upheaval and subsidence may be called *diastrophism*, and we have diastrophic processes. The horizontal movements consist in the transportation of materials from one region to another, generally by the agency of water, but to some slight extent by the agency of wind, and to a very slight extent by the agency of life, for the animals build up materials of the earth into their tissues, and transport them from place to place; but for our purpose we may neglect life agency and wind agency, and consider only the aque-

ous agency. By aqueous agency the rocks are degraded from one region and transported to another, and there built up or constructed into new forms. This may be called *gradation*, and we have grading processes. Hence we have to consider volcanic processes, diastrophic processes, and grading processes.

VULCANISM.—By volcanic processes materials are brought from a great depth to the surface, when they are said to be *extruded;* and sometimes they are brought from great depths and left still within the crust, filling crevices, or pushed laterally between layers of the crust: then the lavas are said to be *intruded.* Of that which comes to the surface, a large part is in a molten or fluid form; but another almost as large part comes out as fragments thrown up by explosions. The lavas that are poured out form *coulees*, or sheets of rock, when they are cooled, and often one is piled on another; and sometimes vents are produced which are kept open for a long time, or periodically are closed, so that there may be a continuous or an intermittent pouring of lava. Sometimes the melted lava is sent to the surface and high into the air by explosive action : cinders are therefore lavas that have been extruded by explosion while yet molten.

Some lavas extruded by explosion come out in the form of fine dust, as if the explosive agency had thoroughly permeated the lava itself; and when the explosion comes, it is torn into the most minute fragments, constituting an impalpable ash. Between dust or ash, cinders or scoriæ, and sheets of lava or coulees, no distinct demarcation can be made: they grade into one another. From the finest dust there are gradations into cinders, and from the cinders there are gradations into coulees; and yet the dust is sent into the air as fragments of ash, and the coulees come to the surface in flowing streams.

The coulees, cinders, and ashes come from the interior intermittently. In a great region of country, like that of the Rocky Mountains or of the Andes, an eruption occurs at one time and then at another, and at one place and then at another. Usually the irregularity of place is very great; so that large areas of country are subject to volcanic activity, and have sheets of lava spread over them—now here, now there—from time to time. But occasionally the eruption is concentrated for a long time at one point, so that eruption follows eruption from one vent, and then volcanoes are produced; but the more common process forms only volcanic plateaus of very irregular outline. Enough, per-



A Coulee of Lava.

haps, has been said to make it clear how the land is built up by vulcanism.

Diastrophism.—This is the uplifting and subsidence of the earth's crust. Why the rock envelope, which must be of enormous weight, is really moved in this manner, is not well known; or, at any rate, no scientific man has explained it in such a manner that all other scientific men agree with him. To the fact of uplifting and subsidence all agree, and to many of its characteristics there is general assent; but no complete explanation of this cause has universal acceptation. We are therefore under the necessity of stating some of the facts of displacement with-

out properly showing their causes. It is well known that the rocks are fractured by great fissures miles in length, or scores of miles in length, or even hundreds of miles in length, and that along these fissures the rocks are displaced. Sometimes the rocks go down or up on one side, and it seems that there are times when the rocks go down on one side and up on the other at the same time, and this may always be the case. When rocks are displaced in this manner, they are said to be *faulted.* Small faults and great faults are found in the rocks. The amount of displacement is called the *throw;* and the throw may be just perceptible, or it may be thousands of feet. In some cases the faults may be but a few yards in length; in other cases they may be hundreds of miles.

Great faults are never made at one movement, but by intermittent small movements following one another in a long succession. Sometimes a fault which is single for a distance will divide into two or more fractures, with two or more displacements; sometimes there is a series of parallel faults, so that the entire displacement is produced by a series of steps. As the faulting is intermittent, and as years or centuries, or centuries of centuries, may intervene between movements, great change may be wrought in the surface along the faults by rains and rivers cutting out valleys and leaving hills. Then from time to time lavas may pour out through the fissures, and flow down into the valleys between the hills, or may even cover up the hills; and when the faulting is renewed, the lavas themselves are fractured. Sometimes these lavas form obstructions or dams in the valleys,

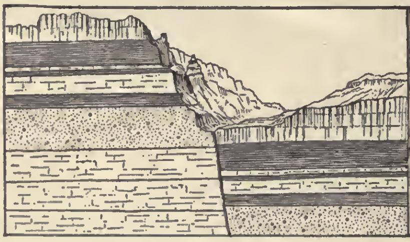


Diagram of a Fault.

Diagram of a Monoclinal Flexure.

and the waters accumulate therein, and sediments are washed into the waters, and sedimentary rocks are deposited in the lakes over the fissures. When the diastrophic activity is renewed,—that is, when the faulting again occurs,—these beds are broken. Regions of country treated in this manner may be again faulted

by parallel fractures, and carved into valleys and hills, and covered with lavas and sedimentary rocks, and broken again from time to time. This may go on for millions of years, and for a long distance, say, hundreds of miles. The total effect of such a series of displacements will make the country on one side of the line of faults very much higher than it is on the other; while the rocks uplifted will be turned up so that they dip away from the faulted zone.

It is thus that we sometimes find a simple fault to be a mere fracture, with a single displacement; while at other times we find complex fractures, with many displacements, and a long history involved.

A Monoclinal Flexure as seen in Nature.

The same amount of displacement can occur under very different conditions. Cut a sheet of paper in two, and arrange the parts on your table so that one of the cut edges lies higher than the other, say, about an inch. Then bend another sheet of paper down and out again, so that on one side of the bend the

paper is an inch higher than on the other. By the two methods you have made two kinds of displacements, — one by faulting, the other by flexing. Now, rocks on the crust of the earth may be bent in this manner, and such bends are called *monoclinal flexures.* Both forms of displacements are common, but faulting is more often seen than flexing.

A series of parallel monoclinal flexures of this kind, not very far apart, produce a series of wrinkles; and we have upturned wrinkles and downturned wrinkles. The upturned wrinkles are called *anticlinal*, and the downturned wrinkles *synclinal.* Such anticlinals and synclinals are usually called *folds*, and so we have anticlinal and synclinal folds. Thus displacement is represented by faults, monoclinal flexures, and folds. Faults change into monoclinal flexures sometimes abruptly, and sometimes gradually, — that is, the displacement may be carried on for a time as a flexure, and suddenly change and become a fault, — so that it is impossible to draw an absolute distinction between faults and monoclinal flexures, and between flexures and folds: one method of displacement runs into another.

The crust of the earth, or the rock envelope, is of great thickness, but just how thick is not known, probably several miles; and these faults, flexures, and folds are found to extend as far down as man is able to study the condition of the rocks. It seems probable that great faults extend quite through what is known to geologists as the crust, and there is some evidence to show that often that which appears as a fault at the surface, appears as a flexure at a great depth; but this is a generalization which must be made with some reservation, because observations have not been carried to such an extent as to warrant the statement that such is the law.

By great faults and flexures the crust of the earth, so far as it is known to man, is divided into great regions scores or even hundreds of square miles in extent; but each of these parts is again broken by smaller fractures called *joints.* Sometimes this shattering is very minute, sometimes it is very coarse; but it is usually more or less regular, so that the blocks are broken into somewhat regular forms. Thus it is that the workman in quarrying rocks never finds them in continuous bodies, but always discovers that they are broken into blocks of greater or less extent.

Perhaps we have presented already all that is necessary on

A Small Anticlinal Fold near Hancock, Maryland.

the subject of diastrophism for the purpose under consideration; namely, to explain the origin and characteristics of the surface features on the earth.

GRADATION.—This process is accomplished through the agency of water. First, the rocks must be disintegrated; second, the rocks must be transported; and, third, the rocks must be deposited. Thus we have *disintegration*, *transportation*, and *deposition*. Rocks are disintegrated by chemical action, with expansion and contraction by changes of temperature. Rocks are disintegrated mechanically chiefly by the abrasion of streams and glaciers. Then rocks are undermined and broken down by gravity in the banks of streams, and in cliffs that are formed in various ways.

The material transported by water must be loaded, and it is loaded by being driven by rains and streams from higher to lower position and by the undermining of banks. The load is heavier than the water, and hence it sinks. The finer the material, the longer and farther it will be carried by the water, while the very coarse material sinks at once. The swifter the current of the stream, the farther the load will be carried. But this is in part counteracted by another condition that springs from the increase of the velocity of the current. As the velocity is increased, the depth of the water is diminished, and the load has a less distance to fall in reaching the bottom. In streams much material is driven along at the bottom as it is rolled over by the force of the current. As a stream flows, the material carried is thrown down from time to time, the more as floods subside, and is reloaded from time to time, the more as floods arise, until as fine sediment it is carried into the still water of some lake, or into the sea, where it is assorted and arranged by waves and currents, and is mixed with the sands and gravels formed on the surf, and finally consolidated into hard rocks.

The rain and the snow are spread over the surface, and wash it all; but the rills that come from snow and rain run in little channels, and these rill channels converge into brook channels, and brook channels into creek channels, and creek channels into river channels. We have therefore two ways by which the land is degraded by water, which should be discriminated: the wash of rain and snow we will call *erosion*, and the cutting of channels by streams we will call *corrasion*. No perfect separation can be made between these two processes; but yet corrasion must be

Marble Canyon formed by the Corrasion of the Colorado River.

discriminated from erosion, for by corrasion deep channels are carved, and some of the most sublime scenery in the world is dependent upon it, for the great canyons are carved by corrasion.

The material transported by streams of ice is loaded in two ways: it falls from overhanging cliffs to the surface of the ice, and it is plucked by the ice from the bottom of the channel. As the ice is divided by cracks and again reunited, some of the surface load of the glacier falls to the bottom, where it becomes imbedded, along with the plucked fragments, in the lower layers of the ice. Exceptionally, and in ways that are not understood, some of the material escapes from the lower surface of the ice, and forms local deposits over which the ice slides; but in the main all the glacier's load is carried forward to the limit of its motion, where the ice melts, and the load is dropped in an irregular heap called a *moraine.* Streams of ice, like streams of water, corrade their channels, using the rock fragments bedded in their lower parts as cutting tools, and the rock flour thus abraded becomes part of the load to be deposited with the rest in the moraine.

It will be seen that we must distinguish three grand processes by which the features of the surface of the earth are produced, —*vulcanism, diastrophism,* and *gradation.* There are other minor processes; but they are so small compared with these, that for our present purpose they may be neglected. All we have hitherto said has had this result in view,—that we might clearly understand the three great physiographic processes.

We have learned of three great moving envelopes, and of how they are in motion; and in studying this subject we have discovered the three processes by which the features of the earth's surface are molded in such a manner that we have seas, gulfs, bays, straits, lakes, rivers, and fountains, and that we have continents, islands, plains, plateaus, mountains, hills, and valleys. How all of these features are produced, and many others of minor importance, must be the theme of another paper.

PHYSIOGRAPHIC FEATURES.

By J. W. Powell.

A volcano in action is a scene of wonder. The storm of rock, the luminous vapor, and, more than all, the exhibition of stupendous force, combine to make it a sublime spectacle. The method by which a volcano is constructed was explained in a former monograph as a part of the great process of *vulcanism*. In the same monograph the manner in which great blocks of the crust of the earth are upheaved, tilted, flexed, and folded, was shown, and the process by which this upheaval is carried on was called *diastrophism*. Diastrophism also has elements of sublimity; not to untrained sense, but only to instructed reflection, that understands the grand energies employed and the mighty works done. Again, it was explained that mountains and plains are carved by rains and streams, leaving behind plateaus, mountains, hills, and valleys; and this process was called *gradation*. The sublimity of the processes of gradation is grasped only by reflection on the energy of the sun in lifting the waters of the sea into the air, and driving them in flocks of clouds over the land, and hurling them in storms to beat the rocks into sands and bear them away to the bosom of the ocean whence the waters were lifted. If these three processes are properly comprehended, then it is possible to understand the origin of the physical features of the surface of the earth, such as continents and islands, seas and lakes, together with such forms as plains, plateaus, mountains, valleys, hills, and many other interesting features.

The ocean covers about three fourths of the surface of the earth; and arms of the sea extend into the land, forming gulfs and bays. Strictly speaking, all lands are islands. The two Americas together constitute an island, and the entire island is sometimes called the Western Continent; and sometimes North America and South America are each called a continent. Eu-

rope, Asia, and Africa together constitute another great island, the largest of the earth. This island is sometimes called the Eastern Continent; and sometimes Europe, Asia, and Africa are severally called continents. Australia is another great island, and is sometimes called a continent. In addition to these great continental islands, there are many smaller islands. All of these islands, continental and minute, — that is, all of the land surfaces of the earth, — have been sea bottom at some time or other, and the waves of the ocean have rolled over them all; they have all been brought above the level of the sea, and have all been fashioned into their present forms by the joint action of vulcanism, diastrophism, and gradation. The ocean has its shores fretted with many salients, as gulfs and bays, all due to the three great processes. How the forms of land and water are produced is the story now to be told.

PLAINS AND PLATEAUS.

Plains.— Whenever in any region the process of slow upheaval comes to an end, and such district is still subject to degradation by rains and streams, the process of reduction goes on until the surface is brought down to the level of the sea or lake into which its waters discharge. At the same time the land may increase in area by the deposit of sediments which have been carried away from its surface and added to its margin: in this manner the low plain is enlarged. A *plain*, therefore, may be due in part to degradation and in part to sedimentation. By one or both methods all plains are formed. The *base-level* of a plain is the level of the surface of the sea, lake, or stream into which the waters of the plain are discharged.

Sea Plains.— The sea-level plain is permanent in the absence of diastrophism, for it cannot be degraded below the action of waves. It will be understood that the land plain which is brought down to the level of the sea has its margin on the seashore, and that it extends back from the shore a distance which may be miles or hundreds of miles. As it stretches back, its surface rises slightly. The whole plain is not brought down absolutely to the level of the sea, but only nearly to that level, so that the water runs off by slow, deep, meandering streams. The wash of the rain over the surface is comparatively little, and the slow streams are usually clear, or, when turbid, are stained with black soil,

but they do not carry great quantities of mud. Such is the typical plain as it borders the sea. Low lands with surfaces more inclined, and with more swiftly running streams, are still called *plains*, though they are not fully brought down to base-level; sometimes they are called *peneplains* (almost plains).

Lake Plains.—Other plains may be formed with their base-level depending upon the levels of lakes. Such plains are in the interior of the land, and may be high above the sea. The base-level of a lake is not permanent, like that of the sea, but is changeable. Every fresh-water lake has an outlet or stream by which it overflows the lake barrier. This stream may cut the barrier down; that is, it may corrade its channel deeper. The deepening of the channel commences below, away from the lake, and progresses back upstream until the lake is reached. Then the waters of the lake rush through the newly opened channel, and the lake is drained in whole or in part. The plain depending upon such a lake will thus have its base-level changed. If a lake is thus partially drained, the new dry land stretches back to the old shore line, where *bluffs* have been formed by the waves. This old shore line with its bluffs is a conspicuous terrace step to the older and higher plain. A lake may change its level in such manner from time to time, and a series of old shore lines may be left, so that a series of plains will appear separated by low terrace steps. Terraced plains are often formed about lakes in this manner.

Stream Plains.—A river may be hundreds of miles in length. As it flows along, it passes through rocks of varying degrees of hardness. Where the rocks are firm and stable, corrasion of the stream is slow; where the rocks are soft, corrasion is more rapid. In this manner the river is divided into lengths, or *reaches.* Along its course where the rocks are hard, the stream is narrow and swift, with rapids and falls; where the rocks are soft, it is wide and quiet. So the river is often a stairway from an upper to a lower region. The slow reach is a *base-level*, like that of a lake, below which the banks and hills on either side cannot be degraded; and local plains are thus formed, which rise gently back from the river. These we will call *stream* plains.

Sometimes another process provides swift reaches to rivers: diastrophism is the agent. There may be a slow upheaval of the land athwart the course of the stream. As the land rises, the river cuts its channel, so that it still flows on: for the faster

the land rises, the swifter is the current; and the swifter the current, the more rapidly the rocks are cut away. So the river corrades its way through obstructing rocks as they rise by dias-

Green River cutting its Channel through the Uintah Mountains as they rise athwart its Course.

trophism. Such an upheaval of rock across the current of a stream may last for a long time, and the river may be held to a base-level for all that time, and extensive plains may be carved.

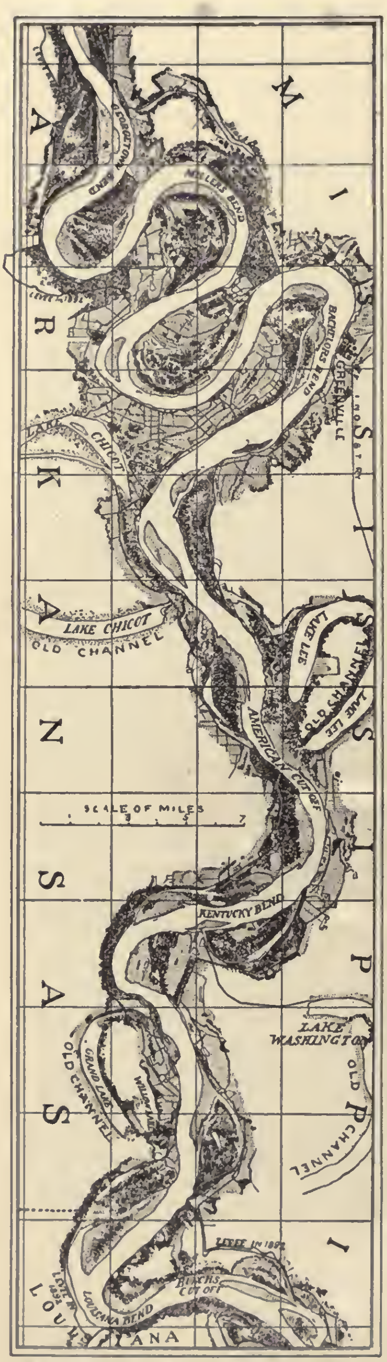
The preservation of a local base-level of a river in this manner is common. In the history of a plain thus formed, terracing may occur like that made by the lowering of lakes. This is accomplished by the cutting away of the swift reaches, which changes the base-level of the slow reach above. So the local plains are sometimes terraced.

Flood Plains.—In the history of a river a slow reach is soon formed immediately above its mouth, where it enters a lake or the sea, and this slow reach is gradually extended upstream until it is tens or hundreds of miles long. In the process of extending the slow reach up-river, the swift reaches in the hard rock are cut out, so that the river has but a low declivity. The stream carries sediment, which it deposits just outside its mouth, and thus a delta is formed. So the slow reach at the mouth of the river is lengthened downstream by the growth of the delta, and upstream by the corrasion of the channel down to the base-level.

River channels are corraded by their own waters, and the streams use the sediments which they contain as the instrument of corrasion. As a river cuts its channel down toward the base-level, it has less and less vertical cutting to perform, and then its energies are turned against its banks. The way in which this is done is of great interest. As the declivity of the stream is less, the water of the stream is retarded in its flow, and the sediment carried in the water is more rapidly deposited because the waters are more quiet; that is, the distance to which the load is carried is shorter. The swift stream carries its load much farther than the slow stream.

A curved stream has slow reaches and swift reaches. Where the water is slow, bars are formed, for there the load is thrown down; where the water is swift, the channel is cut, for there the load is an instrument of corrasion. Against the outside bank of curves the river flows with a swift current, and cuts. Along the inside bank the current is slow, and deposits are formed. A deposit formed on the inside bank throws the water still more against the outside bank. Thus, while one bank is built, the other bank is cut; for on one side the current of the stream is swift, and on the other side the current is slow. These places of deposition and lateral corrasion are modified in many ways that need not be considered here.

As a river ceases to corrade vertically, it gradually begins to



Mississippi River, near Greenville, Miss.

corrade horizontally or laterally. Thus vertical corrasion is turned into lateral corrasion. The banks are cut in one place, and the load is deposited in bars in another. So banks are built and banks are carried away; and when the stream has practically reached its base-level in the sea or lake into which it discharges, all its corrasion is lateral, and the cut at every outside bank adds to the instrument of corrasion, while the bar of every inside bank adds to the force of the water against the opposite side and below, so that the current is thrown against the banks more and more, and loaded more and more, until the rate of lateral corrasion is much greater than was the rate of vertical corrasion.

Rivers subject to lateral corrasion in this manner ever change their courses, plowing to the right and plowing to the left, sending their curves far back toward the hills until curve meets curve in its outer limit, and a *cut-off* is produced. A great river in a flood plain squirms like a great serpent on the desert. With every fold in its long form it cuts away new land on one side, and builds up new land on the other. So such rivers sway back and forth across their valleys, and dig away the land on both sides down to the bottom of their channels, always to build it up again. A wide valley is carved by the river to the level of its bottom, and built up

again in a plain to the level of its high water; and this built plain in an excavated valley is known as a *flood* plain. Such a flood plain may be formed along any quiet reach of the river from its source to the sea.

So we have *sea* plains, *lake* plains, *stream* plains, and *flood* plains.

PLATEAUS. *Diastrophic Plateaus.*— When in a great district of country the process of upheaval has fairly set in, it may continue for an indefinite time; and the land-formed or sea-formed plain may rise higher and higher as the centuries roll by, until it is lifted hundreds or even thousands of feet above the level of the sea. As it is carried up in this manner, rains fall upon it and dig it down, and the streams carry the material away. The principal rivers cut their channels deeper and deeper, the lateral rivers cut their channels deeper and deeper, the creeks cut their channels deeper and deeper, and the rills that run only when the rains fall cut their channels deeper and deeper, so that the rising plain is divided by a multitude of large and small streams; but the summits between the streams remain for a much longer time, and preserve, in a rough way, a general level. The site of the old plain, marked by the hilltops, will long be visible to the skilled eye of a geographer. When a plain has thus been uplifted and carved with stream channels while the hilltops yet remain to mark the surface of the old plain, it is called a *plateau.* Thus plains are due to gradation; plateaus, to diastrophism and gradation. It is manifest that the plain thus gradually merges into the plateau by process of upheaval and gradation. For this reason it is not practicable to clearly discriminate plateaus from plains, and in the common practice of applying names some confusion arises. The same region of country will sometimes be called a plain, and sometimes a plateau; for a plateau is but an elevated plain, and the degree of elevation and gradation to which it must submit ere its name is changed cannot always be determined with exactness.

A great plain, as it is lifted up, may be broken into parts by another agency; that is, by *fracturing* and *faulting;* and the blocks into which it is thus divided may be variously lifted and tilted. In such cases the edge of the plateau may still be defined as the escarpment of a great fault. Such displaced blocks are quite common in some parts of the United States. All plateaus that are formed by the upheaval of plains, and cut into parts by

rivers, or broken into parts by faults, or divided into parts by flexures, we will call *diastrophic* plateaus.

Vulcanic Plateaus.— In the study of vulcanism we learned how volcanoes were formed, and how coulees of lava were poured out on the surface of the earth, and how strata of dust and ashes were spread over the land. Now, dust and ashes poured out in this manner, together with coulees of lava piled up one upon another over a great region of country, may produce a plateau. So we have *vulcanic* plateaus.

A plateau is only a lifted and rather irregular plain, and a plain is a more regular and less lifted plateau. Should we call them all plains, then we would have plains of *gradation* or true plains, *diastrophic* plains (*diastrophic* plateaus), and *vulcanic* plains (*vulcanic* plateaus).

MOUNTAINS.

VULCANIC MOUNTAINS. *Tushar Mountains.*—Vulcanic plateaus are common as great elevations of land composed of coulees, beds of cinders, and accumulations of ashes. Sometimes small cinder cones are found as well-developed forms, and old cinder cones appear more or less degraded. As the lavas are poured out and piled up, streams carve canyons, gulches, and valleys, which from time to time may be again filled with vulcanic material from below. Finally the vulcanic action ceases, and such plateaus are carved into mountains. In the United States the greater number of vulcanic mountains are of this character, composed wholly of vulcanic rocks. More or less modified by diastrophism, they are called *tushar* mountains.

Volcanoes.— We have already seen how mountains are poured out from the interior of the earth through volcanic vents. Such extravasation is always intermittent. Sheets of lava are poured out, and flow down the sides of the mountain, and build it higher. Then the action ceases for years or centuries, to be renewed from time to time. The years of rest are many more than the years of activity, and in them great changes occur. The beds of lava are covered with vegetation; rains and snows fall upon them; and streams wear them away, cutting canyons and excavating valleys, until at last new floods of rock come to destroy old forests, bury old canyons, and fill old valleys. Volcanoes are in this manner built from materials brought from below as molten lava or as cinders and dust; but the process is slow and intermittent,

and only portions of each vulcanic flood remain in the structure of the mountain. When the fires at last cease and the volcanoes are dead, rains and rivers tear them down until the peaks are all carried away, and only fragments are left as columns of vulcanic rock formed in the ancient chimneys.

Laccolitic Mountains.— There is another class of vulcanic mountains of great interest, though not so common as the volcanoes already described. Lava coming from the interior of the earth through the crust or rock envelope does not always reach the surface: it may rise through the lower beds, and come within a few hundred feet of the surface, and force its way laterally between the sedimentary beds, because the lavas have a greater specific gravity than the limestones, shales, and sandstones of sedimentary origin. As the lavas are forced laterally in this manner between the sedimentary rocks, slowly the upper beds are lifted, and great dome-shaped mountains are formed with cores of lava or igneous rock, and strata of sedimentary rock arched over them. The cores of lava are called *laccolites*, and the mountains thus formed *laccolitic* mountains. Rains fall on these laccolitic mountains as upon all others; and the streams formed thereon carve gorges, and sometimes cut through the sedimentary rocks, and reveal the laccolites within.

Table Mountains.—A great sedimentary plateau, while undergoing gradation by rains and rivers, may be rent by fissures, and lavas poured out. The coulees spread over the surface of sedimentary rocks in this manner prevent for a long time the underlying sedimentary rocks from degradation, for the lavas are much harder. As the adjacent country is washed down, the region protected by coulees remains as a plateau, not very large, and is called a *table* mountain.

Imbricated Mountains.— Such a lava-cut plateau or table mountain may become the core of a greater mountain. Around the flanks of such a low mountain new fissures open, through which lavas are poured, and coulees are thus spread over the flanks of the old table mountain. Still degradation progresses, and the valleys about the mountain are excavated deeper; and as this process goes on, other coulees are poured out at still lower elevations. In such manner the core of sedimentary rocks is sheathed with coulees, and a great mountain is formed with its central body of sedimentary rocks, and its covering of vulcanic rocks.

Special forms of vulcanic mountains have been described as *volcanoes*, *laccolitic* mountains, *table* mountains, and *imbricated* mountains.

It must be clearly understood that vulcanism and gradation coöperate in producing vulcanic mountains. The materials are thrown out from the interior of the earth, and piled up in irregular masses, and then fashioned by the sculpture of waters.

Diastrophic Mountains. — We have already seen how plateaus are formed by diastrophism. Beds of rock are uplifted, and tilted more or less; and as great regions are forced up in this manner, the rains fall upon them, and grade them down. Extensive areas that were plains are lifted, and are cut into plateaus by streams, or broken into plateaus by great faults, or divided by great flexures. Then these plateaus are still further carved by clouds, whose greater tools are rivers and glaciers, and whose finishing instruments are brooks and rills. With them the diastrophic plateaus are fashioned into mountains, with canyons, gorges, and valleys intervening.

We have already learned of sedimentary rocks and metamorphic rocks. These metamorphic rocks were formerly deep-seated. They were at one time sedimentary and igneous rocks, lying in strata, great beds, and masses, and were afterward covered by sedimentary rocks; that is, their stratigraphic place is below the unaltered sedimentary rocks, but in the upheaval of great plateaus these deeply seated rocks have come to the surface, and often constitute the rocks found at the summit of high mountains. Mountains of this class often have a core of metamorphic rocks, with sedimentary rocks inclined on the flanks. Sometimes the sedimentary rocks are carried away, and it may be that such plateaus were formed in metamorphic rocks where sediments have not subsequently been deposited over them, though this is not known with certainty; yet we do know that there are mountains which seem to be composed of only metamorphic rocks, though it is probable that they are only fragments of plateaus whose overlying sedimentary beds have been carried away. Many of the mountain ranges of the world have metamorphic cores with sedimentary beds on their flanks. Many mountain ranges are composed exclusively of sedimentary beds, and other mountains of metamorphic rocks, while all vulcanic mountains have another structure.

Thus in diastrophic mountains three varieties are to be noted,

—*metamorphic* mountains, mountains *with metamorphic cores*, and *sedimentary* mountains. Again, we must note that diastrophism is the agency by which great blocks have been uplifted, and that the minor mountain forms are due to gradation.

GROUPING OF MOUNTAINS.—Volcanoes are sometimes isolated, but they are more often grouped in assemblages of great and small peaks.

Diastrophic mountains are commonly arranged in lines, and are then called *ranges*. Thus a number of mountains may be carved out of a huge wrinkle which would have formed a great round-backed plateau, had it not been for the water. Such great wrinkles are sometimes parallel with one another, and thus ranges are grouped into *systems of parallel lines*. The ranges themselves may be complicated, and associated with vulcanic mountains. The wrinkles of which ranges are formed may not stand abreast of one another, but one may overlap another; that is, extend beyond it in one direction, while the first may extend beyond the second in the other direction. Mountain ranges lying in this shape are said to be in *echelon*. Parallel ranges and echelon ranges are sometimes complicated with vulcanic mountains, and may extend over great geographic areas as extensive mountain systems. Between the ranges great valleys lie, and between the mountains of every range smaller valleys are formed.

And yet there is another way in which mountains are grouped. A great district of country may be upheaved as a block hundreds of miles long and scores of miles wide. One edge of the block may be much higher than the other; then the streams that gather on the block roll from the upturned margin down with the dip of the beds into the great valley or plain below, and carve gulches and valleys across the block. Such ranges are more or less transverse to the longitudinal direction of the block. Thus great spurs are formed extending from the crest to the great valley. Such a system of mountains may be composed of more or less parallel ridges that stand abreast of one another in a long line. These ridges usually have culminating peaks on the side where the block was lifted to the greatest altitude. The Sierra Nevada is a system of mountains of this character. Others on a scale less grand are found in various parts of the United States.

Now, it must be clearly understood that in explaining the character of various mountains it is not possible to make a

classification which can always be clearly demarcated. It has been shown that plateaus are sometimes partly vulcanic and partly diastrophic. As regions are lifted, vulcanic forces are aroused, so that diastrophic mountains are often complicated with vulcanic mountains. A fissure is gradually produced, upon one side of which a block is uplifted to be carved into mountains. At the same time, lavas are poured through the fissure, and mountains are built. Along such fissure a complex range is formed, one side of which is of diastrophic origin, the other side of vulcanic origin; and the peaks of such a range may be in part vulcanic and in part diastrophic. Yet in other but minor ways the two great classes of mountains are complicated with each other, but it will be clear that mountains express the difference between elevating processes and grading processes.

VALLEYS.

Plateaus and mountains afford the most picturesque scenery for the delight of man, but on plains and in valleys he chiefly makes his home. As plains and plateaus are classified by the great physiographic processes, and as mountains are classified in like manner, so valleys fall into three great groups, though this classification must not be understood as implying that the classes can always be clearly distinguished.

Vulcanic Valleys.—When groups of volcanoes are constructed of coulees, cinders, and ashes, valleys are formed between the mountains. The rains and streams modify these valleys, enlarging them, and excavating stream channels; but the origin of such valleys is to be found in vulcanism.

Diastrophic Valleys.—When lands are uplifted in broken blocks or great folds, the lowlands constitute valleys. Such *diastrophic* valleys are also modified by gradation.

Many valleys are inclosed in part by vulcanic mountains, and in part by diastrophic mountains.

Valleys of Gradation.—Upheaved plains are divided into plateaus by the corrasion of streams, and the plateaus also are trenched. As time passes on through geologic ages, stream channels are widened into valleys, and a ramifying system of stream channels into great valleys. Systems of streams uniting with systems of streams carve still greater valleys. Most of the valleys of the world are produced in this manner.

Thus we have found *vulcanic* valleys, *diastrophic* valleys, and *gradation* valleys. *Compound* valleys produced by all these agencies are found.

HILLS.

Over all the land the hills are scattered. Hills rise from plains, hills are embossed on plateaus, hills are grouped about mountains, and hills are scattered through the valleys. No definite distinction can be made between hills and mountains. The smaller forms are usually called hills; the larger, mountains; but the usage is not consistent. Forms that are called mountains in one region would be called hills in another, and *vice versa*. Where there are great mountains in sight, somewhat smaller forms are often called hills; while in another region forms of equal magnitude would be called mountains.

VULCANIC HILLS.—As vulcanic plateaus are carved into mountains, these mountains are still further carved into hills, and we have hills of gradation composed of vulcanic rocks. Vulcanic hills are chiefly of this character, but there are other kinds that require mention.

CINDER CONES.—As vulcanic fires go out, the expiring energies often build cinder cones; and over a vulcanic region cone-shaped hills are found, often much worn down by rains.

COULEE HILLS.—When molten matter is poured over the surface of the earth in coulees, it slowly congeals, and slowly moves in great sluggish waves, and the red-hot rock is transformed into cold black rock. In this manner waves of liquid rock are frozen into somber hills of low magnitude. So a great coulee often presents a surface of hills and valleys as wrinkles of the waves by which it progresses.

DIASTROPHIC HILLS.—Uplifted plains form plateaus, and these plateaus are carved into hills and mountains, while the mountains themselves are at last dissected into hills. Thus we have hills in diastrophic blocks carved by waters. The carving of plateaus and mountains into hills is accomplished not only by running water, but also by glaciers.

Diastrophic hills present some interesting relations. As the edges of plateaus are carved, the summits of the hills do not appear above the general level of the plateau itself. Ridges between valleys carved in plateaus may be sharp; and as they are progressively degraded, the more narrow portions may become

gaps; and as these gaps are still further degraded, the tops of the hills are lowered. Thus some hills may have their summits at the level of the plateau; other hills, below it. As the process goes on, the whole plateau may be cut into hills of irregular altitudes. As the process still goes on, and the valleys are enlarged, the hills become more unequal in height, and fewer in number. In the same manner mountains are carved into very irregular hills. Thus it is that we may ascend hills in going from lower to higher districts of country, and such hills will not have declivities on all sides; while in older regions of degradation, where the plateau structure is wholly or in part lost, the hills are much more irregular, and it is necessary to descend from every hill in order to reach and climb one adjacent. Hills thus isolated are sometimes called hills of *circumdenudation*, while hills which extend from the summit of plateaus to plains below may be called hills of *partial denudation.*

GRADATIONAL HILLS.—Glaciers build hills of their own. They dig down mountains and plateaus, and carry the material into the valleys and over the plains, and deposit it in hills. The débris carried by glaciers forms *moraines.* When glaciers melt, this material is left in irregular heaps, and is still designated by the same term. Old moraines are often conspicuous. They are irregular, and frequently contain hollows which hold lakes. *Terminal* moraines usually appear as curved ridges across the course of the ice stream by which they were formed. *Lateral* moraines form sharp-crested ridges, and mark the margin of departed glaciers. Other varieties of hills due to the same agency are named with reference to their relation to the ice which formed them.

Besides the more general morainic deposit left by glaciers, there are interesting and frequently very conspicuous topographic forms produced by special agencies.

Long tunnels are sometimes melted out beneath ice sheets, and become filled by streams with gravel and sand. When the ice melts, these deposits are left as long, winding ridges, termed *eskers.*

About the moraines of glaciers where streams discharge piles of gravel and sand, high hills are formed that have billowy surfaces, and are known as *kames.* The popular name for a group of kames in certain regions is "kettle hills," in others "cup-and-saucer hills;" the cups being turned upside down and forming

rounded knolls, while the saucers between hold water and form lakelets.

As an ice sheet begins to melt, streams may form on its surface, and cut for themselves channels, in which lodges the fine débris imbedded in the ice; and this material sometimes remains in long ridges of loam, called *paha* in Iowa, where they abound.

The débris carried out by moving ice masses may lodge, perhaps, on a nucleus of rock, and the ice moving over the obstruction gives a smooth whale-back form to the hill. These deposits are sometimes termed *lenticular hills*, or *drumlins.* The longer axis of such hills lies in the direction of the ice movements.

These types of hills formed by glacial action are the most common, and are characteristic of many regions, but other forms are known; and in many instances the different types are so commingled that they are not easily distinguished.

Sand Dunes.—And yet there is another class of hills interesting to the geographer, formed by the drifting of the sand by prevailing winds. On the shores of the sea the rocks are ground into sands, and long, fringing sand beaches are produced. Then the winds carry these sands away, some to the sea, and some to the land. Such land-drifting sands are formed into hills, which are known as *sand dunes.* Lake shores and river banks have their sand beaches, and deserts often present great stretches of naked sand, all of which are drifted into dunes. All dunes travel. The sand is carried from the windward side and deposited upon the leeward side, and so the hills journey. So we have *seabeach* dunes, *lake-shore* dunes, *stream-bank* dunes, and *desert* dunes.

CLIFFS.

Cliffs of Gradation.— Streams with great declivity rapidly corrade their channels. In cutting down through hard rocks, the banks remain as *cliffs.* As the process of corrasion goes on, and the channels are cut deeper, the cliffs extend higher above the water. Channels inclosed by cliffs in this manner are usually called *canyons*, the walls of which are cliffs of beauty. But the cliffs break down by gravity. The waters percolating through the joints of the rocks, and streaming down the mural faces, gradually break them up; and they fall, and are piled up below in a *talus* of loose rocks, which is still further

worn away by rains, and carried into the streams, where it is transported away. In this manner the canyons are gradually widened, and the cliffs become steep banks, and the channels are then usually known as *gulches;* but the gulches themselves

Cliffs of the Canyon de Tseyi, Arizona.

increase in width as the process of degradation goes on, until *valleys* separate the distinct banks, which are themselves carved into hills. Sometimes the banks retreat by a peculiar process

known as *sapping.* Harder and more coherent beds above are underlaid with softer and more friable beds below; then the rocks below are carried away more rapidly than those above. Thus the retreating walls are forever undermined, and the rocks break off above by the force of gravity, to be ground more or less in the fall, and to be washed away with the talus below. Thus a cliff is maintained which retreats slowly through the centuries of degradation. In the same manner the valley is widened continuously while yet walled with cliffs.

As the land still rises by diastrophism, the stream still cuts by corrasion, and may cut through harder and softer rocks in alternating strata or beds. In the upper rocks the cliffs are carried far back from the stream, and another line of cliffs may be established under the same conditions, the upper part being composed of hard beds, the lower of soft beds, and another line of cliffs may thus follow the wake of the first. The traveler may climb a cliff wall of a canyon, then walk for a distance, often miles, to a second line of cliffs, which he climbs, and can pass over comparatively level land for a distance, more or less, until another line of cliffs is reached. Thus cliffs rise over cliffs, forming a series of great steps from terrace to terrace.

Such cliffs are not regular in the lines of their faces. The river itself is meandering, and so the lines of cliffs are meandering. Then lateral streams may cut through them, running to the main river, and break them with canyons; and these lateral canyons also are expanded into valleys, and the terraces are thus carved into blocks with retreating walls. The second system of canyons may be traversed by a third system, and the terraces may thus be carved in many ways; and as the process of degradation goes on, the terraces may ultimately be greatly obscured, and at last carved into hills of circumdenudation, which are *buttes;* and finally the beds may be reduced to monuments and bowlders of rock; but canyon walls, terrace faces, buttes, and monuments of cliff structure, remain until the region is brought down to low hills. The canyons themselves are features of grandeur; the cliffs are conspicuous for strange and fantastic majesty; the buttes present lone, towering forms that challenge admiration; and the monuments may appear like gigantic forests of stone tree trunks, gnarled, fantastic, and picturesque.

Valleys sometimes extend back into high plateaus. When

the upper surface of such a plateau is of hard rock, and the rocks beneath are soft, the head of the valley may be an amphitheater whose walls are cliffs. Sometimes the traveler may ascend such a valley from the plain below until he reaches a cliff, when the walls must be scaled, or he must turn to one side and climb the hills, to reach the summit of the plateau. Such amphitheaters are called *coves*. Valleys heading in mountains may have coves; when they are refashioned by glaciers, they are known as *cirques*.

On seacoasts and lake shores, sapping is carried on by the waves, and *cliffs* are often produced.

A Shore Cliff on Chesapeake Bay.

Diastrophic Cliffs.—When great blocks of land are severed by great faults, and tilted, the broken faces of the uplifted edges of the blocks stand in great lines of cliffs. Such diastrophic cliffs retreat by degradation through the agency of sapping, so that they are finally converted into gradational cliffs, with all the characteristics of cliffs of the first class.

Often they are complicated in another manner. The fissures of the folds by which the blocks are displaced may give vent to lavas which modify and obscure the cliffs. In regions of this character, which are quite extensive in the United States, many of the cliffs of diastrophism are thus in part developed into slopes

by vulcanic rocks piled against them. Usually the coulees pour out a flood below; but coulees may be piled on coulees, until at last the accumulation of lava becomes so high as to flow over the margin of the terrace, and build low mountains along the lines of faults. Occasionally in such places volcanic cones are formed.

Cliffs of Vulcanism.—Coulees of lava pour from the vent and flow down the slopes of mountains and plateaus. Some

A Coulee Cliff in New Mexico.

lavas are excessively fluid, and flow in thin sheets; others are but slightly fluid, and flow in thicker sheets; all cool as they flow, until at last they come to a standstill. When the rock ceases to flow in this manner, the lavas behind pile upon it; and coulees are often formed with very rough edges, which constitute cliffs that may be scores or hundreds of feet high. Such cliffs may

also be undermined by sapping, and carried back more or less, as in the case of cliffs of degradation.

Thus we have cliffs of *degradation*, cliffs of *diastrophism*, and cliffs of *vulcanism*.

SPECIAL FORMS.

BUTTES.— Scattered over the land, a great variety of special forms and minor features are observed which add beauty to the landscape, and interest to the study of the physiognomy of the

Butte near the San Juan River, Colorado.

land. Hills are found with more or less precipitous cliffs or steep slopes, that stand alone as monuments of circumdenudation. These may be called *buttes*.

MONUMENTS.— Monuments, or pillars of rocks, are often left standing in the great process of degradation; for capping stones of great hardness sometimes furnish protection to underlying, softer beds. Such monuments may be tens or scores or hundreds of feet in height; and where grouped in large areas, they are sometimes called "monument parks."

DIKE WALLS.— Sometimes crevices in the rocks are filled with lavas from below; then the lavas cool into rocks of a firmer texture than those of the adjacent formations; afterward, by degradation, the softer rocks on either side are carried away, and the lava rocks stand in walls. Lavas intruded in this manner are called *dikes*, and dike walls are common in volcanic regions.

Volcanic Necks.—Volcanic cones are often composed in large part of ashes, cinders, and readily disintegrated coulees; but the throat of a volcano is usually coated with hard material which has come up in a flood from below and formed a chimney lined with very hard rock, and finally these chimneys are completely filled with hard rock. In the process of degradation the exterior and softer materials are carried away, and the filled chimneys of hard rock stand as tombstones of the dead volcanoes. These are called *volcanic necks.*

Bowlders.—In the corrasion of stream channels and the excavation of valleys and the degradation of hills, bowlders of harder and more coherent rocks often remain behind, while the softer materials are carried away by the waters. Thus the landscape of hilly regions is often strewn with rocks of many fantastic forms, and the remnants of hills and ridges often lie in piles of water-worn bowlders.

Great floods also move large blocks of stone, and sometimes scatter them over the valleys; and wherever stream channels have much declivity, bowlders line the banks and shores, and along the channels are strewn gravels worn into rounded forms by being rolled about in the rushing waters.

Glaciers are great agencies in distributing rocks, gravels, sands, and clays over surfaces of land, as they silently creep onward, or sometimes move in more rapid progress, to the sounds of breaking and crushing ice.

In the vicissitudes of hill making, ledges of hard rock often protrude through the mantle rock.

Thus in varied ways the rocks give charm to the landscape. He who understands the subject of physiography, and who has his eyes open and his mind receptive to the teachings of nature, not only discovers beautiful forms and wonderful compositions of forms, but at the same time reads a lesson of the processes of nature and the great forces silently but irresistibly at work to fashion the earthly home of man.

STREAM CHANNELS AND CATARACTS.

Stream Channels.—When the fields are unplowed, the rains wash away comparatively little earth. The streams flowing in the forests are held in the grass and under the fallen leaves, and slowly creep away to feed the rivers with clear water; but when

man comes to grade and travel his highways, and plow and excavate for his many purposes, the loosened, unprotected earth is soon swept away by rains, and fed to the streams. Thus man changes the aspect and regimen of the rivers. Sometimes, for various reasons, fields are abandoned; and these old fields, destitute of their forests and channeled with furrows and ditches, soon become a prey to rains, and by them the soils are washed away, the declivities are cut by a ramification of storm-water channels, while small, naked hills are left behind that are nearly worthless for agriculture. It is thus that man increases the floods by his labors, and destroys lands by his neglect. All declivities can be injured by careless plowing, and then the richer soils are rapidly borne away.

When the evaporation in any region is almost equal to the precipitation, no streams would be formed, were it not that the rains fall occasionally in great quantities for short periods of time. When such storms come, a multitude of storm-water streams are produced, which are soon dried up. The more permanent streams have periods of comparatively great flood and great drought. About the mountains and plateaus, and generally on the highlands, there is greater rainfall, and many perennial streams are found whose waters run to lower lands, where the rainfall is less. Gradually such streams lose a part of their waters by evaporation, and, though of considerable magnitude in highlands, become very insignificant in the lands below. It is thus that many creeks and rivers in the western portion of the United States carry a greater volume of water near their sources than near their mouths. As such streams gradually diminish, the winds blowing over desert plains drift the sands into their channels, and greatly choke them. The water coming from above into such sands spreads through them, and is evaporated. Where this is the case, such regions of evaporation at the end of dying streams are called *sinks*. Below such sinks the channels may often be lost for a long time. Maximum storms come sometimes,—years apart, ten, twenty-five, or a hundred years, as the case may be,—and by these great storms the sinks are sometimes washed out, and the channels below opened again, and the rivers once more flow, to be filled again during long periods of more evenly distributed rainfall. Such buried stream channels are common throughout the western half of the United States, and have caused great wonder to people who do not understand their

origin and character. As the streams have diminished, the people have often supposed that the climate was changing, and brought in evidence the fact that the rivers were drying up; or when the streams have been opened by a great flood, and rivers have appeared where they seemed not to have existed before, the people have thought that the climate was becoming more humid, and promised a greater supply of water for the use of man.

Many of the streams of the arid region present another phenomenon of great interest. Where the lands are arid, the streams must have steep channels in order to corrade deeply. Many streams have a declivity which would be considered great in humid lands. Streams so choked by dust storms, and the wash of the naked lands on either side of their channels, are protected from vertical corrasion by the accumulation of mud upon the channel floors. Under these circumstances, lateral corrasion prevails, and wide, shallow channels are produced. There are streams, like the Platte or the upper Arkansas and many others of the Great Plains, that are hundreds of yards wide and only a few inches in depth at the ordinary stage of water, and never very deep at the highest floods. Such rivers, though they carry an abundance of water, are not navigable. They are ever loaded with new materials by floods and rains, and remain turbid, and often are rivers of mud with channels beset by quicksands.

From the explanation which has been given, it will be clear how streams carve their own valleys. In studying the history of such streams, unless all the facts heretofore set forth are properly understood, the geographer is apt to err in supposing that the great valleys are to be explained in another manner. It has often been supposed that they give evidence that in a time long past the rainfall was greater, and that by secular change the climate has been transformed from a more humid to a more arid condition, and that with the transformation the streams have gradually become less and less. Such errors have gradually disappeared, as the methods of stream cutting have come to be more clearly understood. Thus flood plains, old channels, terraces, and retreating cliffs are now understood to be caused by the streams in a long history of valley making, and they are no longer believed to furnish evidence of greater rainfall in antiquity.

CATARACTS. *Gradational Cataracts.*—We have already seen that streams have short, rapid reaches that intervene between

long, quiet reaches. These short reaches are mainly due to the hard rocks which compose their channels. In the corrasion of these rapid reaches, the tendency is to cut out the channel at the lower end of the reach to the base-level of the more quiet waters below. This tendency is accented by another condition: if the quiet waters above the rapid are expanded into a broad channel, and especially when lakes are formed, the sediment carried by the river is deposited before reaching the rapid. More and more this sediment is deposited as the upper quiet reaches are expanded into lakes, so that the current is almost wholly checked. The load or sediment which the waters contain is the instrument of corrasion; and when this instrument is lost in the quiet waters, corrasion is checked. The waters flowing from the lake above are comparatively pure, and, disarmed of the weapons of corrasion, they pour into the rapid reach. Here they gather new sediments, and accumulate them in their passage, so that the farther they flow, the greater the amount of sediment they contain, and the more vigorously they corrade. Thus the rapid reaches are cut down progressively from below upward.

At the point where the rapid waters meet the quiet reach below, an elbow of declivity is formed, at the bottom of which an excavation is made; and this basin holds a comparatively large body of water, which is kept in motion by the stream rolling down from above. The water of this basin, ever stirred into activity, is constantly undermining the rocks; and the disintegrated material is loaded on the water and carried away, to be deposited not far below. As the basin retreats upstream, it steadily enlarges, and an incipient cataract, or a *cascade*, is soon produced, the fall of which increases from stage to stage. Now, if this basin is in soft rock, as in clays or shales, while the rocks above are hard,—a condition often found,—then the rapid reach cuts back and increases the distance of the fall until a *cataract* is developed. Most of the great cataracts of the world are formed in this manner, the two most important conditions being, first, that the basin should be in soft rock, and the fall over hard rock; and, second, that the waters should be ponded above in order that the instrument of corrasion should be deposited, and thus permit the action to be carried on chiefly by sapping.

There is a condition under which cataracts of great altitude are produced, though they usually carry but small quantities of water. When the great streams carve canyons, and small streams

A Cataract in Georgia.

enter these canyons, the rate of corrasion of the great stream may greatly exceed that of the small stream; and thus most interesting little cataracts are formed, which often break into spray before reaching the floor of the canyon, and their own corrasion is thus largely prevented. Streams of water woven into a filigree of spray in this manner are often called *bridal veils.*

Diastrophic Cataracts.—When streams flow across faults or monoclinal flexures that are in process of displacement, rapids and often well-developed falls are produced; but such cataracts have a short existence. Where the conditions are favorable, they speedily cut back, and become falls of the first class.

Vulcanic Cataracts.—Coulees of lava frequently pour across streams, and, cooling, dam the waters back in ponds and lakes. Under such conditions cataracts are formed. A few of the great cataracts of the world are of this character.

Thus we have *gradational* cataracts, *diastrophic* cataracts, and *vulcanic* cataracts.

FOUNTAINS.

Springs.—Water and air both circulate through the mantle rocks, which are in the main rather loosely aggregated. The

igneous, sedimentary, and metamorphic rocks are broken into fragments, large or small, by faults and joints, so that there is a circulation of water and air through them also. This underground water comes to the surface in *springs* on low ground, as on the sides of hills, in valleys, and in the banks of streams; and as the water is supplied on the surface of the ground, it finds its way down and out by great numbers of springs, but it must be understood that the supply is primarily derived from the clouds.

Mammoth Springs.— Where there are great accumulations of sand and gravels, forming hills and ridges many square miles in extent, underlaid by impervious formations, *mammoth springs* are sometimes developed. The rain falling upon the surface sand percolates to harder rock below. Thus rills and brooks are formed on the upper surface of the hard rock, below the sands. Brooks, creeks, and even small rivers may be formed in this manner, and may issue in valleys as mammoth springs. In such a case a single spring may give rise to a river large enough to float a steamboat, the head of the river being a great spring.

In volcanic districts great accumulations of cinders, especially in mountain cones, present the conditions favoring the formation of such mammoth springs.

Hot Springs.— In regions where the rocks at and near the surface are of late volcanic origin, so that the rocks are still hot at a moderate depth, the waters circulating through the fissures reach these hot rocks, and *hot springs* are formed.

Geysers.— Sometimes steam accumulates in reservoirs of water below, until it explodes, and the waters are expelled with violence in intermittent bursts. Such hot springs are called *geysers*.

Hot water is a great solvent, and it usually reaches the surface strongly charged with mineral matter from the rocks through which it has passed. Cooling in the open air, the water deposits much of its dissolved matter, which often accumulates about hot springs and geysers in mounds, and decorates basins and terraces with beautiful filigree forms.

Wells.— Wells are dug into the rocks to tap the underground waters. Waters gathered in such reservoirs are mainly derived from the loose rocks of the mantle, but sometimes wells are sunk into strata pervious to water. All such waters dissolve the soluble materials of rock, especially limestones and iron ores.

Hot Springs of the Yellowstone Park.

Waters charged with lime are usually said to be *hard*, while waters charged with iron are called *chalybeate*.

Artesian Wells.— Sometimes a supply of water is discovered in this manner, whose source is in distant rocks that come to the surface at higher levels, and the hydraulic pressure therefrom causes the water to flow over the mouth of the well. Such are *artesian wells*. The pressure may be so great as to throw a column of water high into the air. A spouting well is a fountain of clear water and a fountain of beauty.

CAVERNS.

Gradational Caverns.—It has already been seen that waters percolating in hills and mountains dissolve certain rocks. Where this action goes on above the base-level of the country, such running waters flow out by springs, and are carried away by streams. Underground streams are formed in this manner, that carve underground channels, which are enlarged by the action of the waters in dissolving their walls. Thus *caves* are formed. When a stream comes through some harder rock of limestone, and reaches a soft sandstone that easily washes away, the limestone is undermined as the sandstone is carried away. Then channels

having underground streams may be produced on a grand scale, in part in the sandstone below, and in part in the fissured limestone above. In this manner great separate chambers are formed in the limestone, with communications below in the sandstone. Such is the structure of Mammoth Cave.

In the walls of canyons and in cliffs formed by all processes, caves are produced by sapping. The softer materials below weather out and are carried away by water, and the harder rocks above are left as overhanging ceilings.

Grottoes of this character are often very beautiful, and are sometimes roofed amphitheaters large enough to shelter regiments of men. Sometimes springs issue from such caves and take active part in their production; and lakelets may be formed which are fountains of cool, crystalline water. In arid lands the vegetation springing up about such springs is luxuriant, while in humid lands the mouths of caves are often portals festooned with lichens, liverworts, mosses, and many beautiful flowering plants.

VULCANIC CAVES.—Caves are often found under coulees of lava, for the soft earth is easily washed away.

Sometimes the streams of lava are very fluid, and cool at the bottom and upper surfaces much more rapidly than in the interior. The rocks thus formed remain, while the interior molten lava flows on, and caves are formed in this manner which are known as *volcanic pipes.*

Thus we have *gradational* and *vulcanic* caverns.

LAKES.

Of the rain which falls upon the earth, a part is evaporated and a part gathered into streams. Along the courses of many streams there are basins, which gather the water in lakes where another part is evaporated.

If these basins overflow, the waters of the lakes are sweet; but if they have no outlet, the waters are salt. Much water evaporates from every lake; and if the surface is so great as to give an evaporating area sufficient, or more than sufficient, to dry up all the waters coming down in the streams, then no outlet is necessary or possible. But the waters coming from the land dissolve its salts, and carry them into these lakes; and as the waters escape by evaporation, the salts remain. Thus great accumula-

tions of common salt gather in the lakes of arid regions, and hence their waters are saline. We must learn how these basins which hold the lakes are formed.

DIASTROPHIC LAKES.—In the displacement of the crust of the earth by faulting and wrinkling, depressions are made, and into these basins the waters are gathered by streams, and lakes are formed. Most of the great lakes of the world are of this character. Let us call them *diastrophic* lakes.

COULEE LAKES.—Sometimes volcanic lavas are poured across valleys, and thus the channels of rivers are dammed. These volcanic dams are common, and some rather important lakes are formed in this manner. Geologists call a sheet of lava a *coulee.* Let us call such lakes *coulee* lakes.

CRATER LAKES.—Occasionally lakes are found in the craters of extinct volcanoes. Crater Lake of Oregon is a beautiful illustration, and there are several such lakes in the northern part of Arizona.

BAYOU LAKES.—At great flood times, rivers may leave their channels and cut new ones, and afterward the old channel may be closed in such a manner as to form sites for lakes. Let us call these *bayou* lakes.

GLACIAL LAKES.—Glacial rocks make dams across valleys, and glaciers carve basins. When a region of country is redeemed from the glacial condition by the melting of the ice, such basins are filled with water, and lakes are formed. In the northern parts of the United States a great many of the smaller lakes are of this character, and many such lakes are found in the Rocky Mountains. Let us call them *glacial* lakes.

Thus we have *diastrophic* lakes, *coulee* lakes, *crater* lakes, *bayou* lakes, and *glacial* lakes.

MARSHES.

HILLSIDE MARSHES.—It has previously been shown that the mantle rocks creep down the slopes of hill and mountain. Where the grounds are favorable for their retention, they often accumulate to a greater or less thickness. Into such accumulations the waters percolate from the rocks on the slope above, and from the rains that fall on their surfaces. In such manner hillside and mountainside marshes are produced, which are often called *bogs*, and are quagmires which tremble under the tread of man, and in which many hoofed animals are caught.

Great accumulations of this general character sometimes have their lower portions carried away by gradual degradation, when their marshy contents yield to the force of gravity and escape to a region below. Such movements are called *landslides*. They are often destructive to hamlets, gardens and fields, and sometimes to domestic animals and human life. When lakes are drained, their old beds often become marshes in which rank vegetation may accumulate to form *peat*. About the margins of lakes extensive marshes are sometimes found.

Flood-plain Marshes.—We have seen how flood plains are graded by the overflowing water of streams. The surface left is more or less irregular, and depressions often exist where marshes are formed, and peat sometimes accumulates. Where flood plains are broad, the lands adjacent to the rivers are often higher than the lands farther back. These low grounds nearer to plains and hills often become the sites of marshes; and it may be observed that marshes sometimes separate good agricultural lands near a stream from hilly lands farther away.

Coastal Marshes.—Coast regions sometimes sink and become marshes, or rise out of the sea to form marshes; other coasts are degraded until they become marshes; still other coasts are enlarged by the accretion of sediment to their margin; while fringing islands are produced, and marshes are formed between such fringing islands and the mainland. These coastal marshes are flooded by tides with the salt water of the sea, and they are also flooded by the fresh water of the streams that come from the land. By this cause their waters are often brackish. Where the zone of marsh is wide, the salt water sometimes becomes fresher and fresher from seaward to landward. In a few regions the salt water is clearly demarcated from the fresh water, for certain trees and other plants grow with great luxuriance in brackish water; and as they die and fall to the ground, they are filled with shells, the shards of animals, and to some extent with sediments, until a bank or division is established between the waters of the ocean and the waters of the land.

COAST FORMS.

Gulfs, Bays, Sounds, and Straits.—The seacoast and lake shores of a sinking land are often deeply indented with bodies of water, while the shores of a rising land are more regular.

The islands that stand before the land add much to this irregularity. Behind the islands and within the indented coast, *gulfs*, *bays*, *sounds*, and *straits* are found. These terms are used in a very confused manner. There is a tendency to call the larger bodies gulfs and the smaller bodies bays, while there is the same tendency to call the larger connecting bodies sounds, and smaller, narrow connecting bodies, straits. Under these circumstances, no classification by varieties can be made, but only the tendency of usage can be pointed out. All of these bodies may be classified as *vulcanic*, *diastrophic*, and *gradational.*

PROMONTORIES, CAPES, PENINSULAS, AND ISTHMUSES.—High points of land extending into the sea are often called *promontories*, lower points are often called *capes*, and points nearly cut off from the mainland are often called *peninsulas*, while the necks which connect peninsulas with larger bodies of land are often called *isthmuses;* but there is no very well established usage for these terms, and the nomenclature is rather indefinite. All these forms may be classified in the three great categories.

ISLANDS.

VULCANIC ISLANDS.—When fires break forth to pour their floods of lava into the waters, they may build up *vulcanic* islands. In tropical lands such islands are often fringed with coral reefs.

BARRIER ISLANDS.—Lakes have a special class of islands not found in the sea. When coulee lakes are formed, and valleys are filled with water, the higher portions of the valleys often remain as islands. Thus we have *barrier* islands.

DIASTROPHIC ISLANDS.—When lands subside beneath the sea, higher portions may be left as islands. Thus we have islands of subsidence, and we may call them *downthrow* islands. In the same manner, when sea bottoms are lifted above the level of the ocean by diastrophic agency, in wrinkling or faulting, the higher portions may first appear as islands. Thus we may have islands of upheaval, and call them *uplift* islands.

GRADATIONAL ISLANDS.—When the detritus is brought down from the land by streams, it is carried into the sea, and by the currents distributed along the shore, and mingled with the detritus formed by the beating waves. In this manner such detritus islands are often formed. They may be called *fringing* islands.

A sinking land is itself cut into hills and valleys. As it goes down, the valleys are filled with water; and the hills may remain as islands, or may present an irregular line of shore to the sea. The waves continually encroach on this shore. Where the rocks are soft, the wear is rapid; where the rocks are hard, the wear is slow. The inlets formed by subsidence are enlarged by the encroaching sea. Two such inlets lying somewhat parallel to each other may send out arms into opposite sides of a tongue of land; and, as these arms extend backward, they may finally cut off portions of the land and form islands. These may be called *gulf-cut* islands.

Streams sometimes change their channels at flood time, new channels being cut; and islands are thus formed between the old and the new river beds, and remain as such until the old channels are filled or blocked, so as to become lakes. Such cut-off islands are very common about the deltas of great streams. They may be called *river-cut* islands.

Again, when lakes are formed by glaciers and the lowlands flooded, the hills may remain above water as islands. Thus we have *glacial* islands.

An attempt has been made to characterize the physiographic features of the earth, mainly as they are dependent upon the three great physiographic processes, and to show how fire, earthquake, and flood have been involved in fashioning the land and sea.

PHYSIOGRAPHIC REGIONS OF THE UNITED STATES.

By J. W. Powell.

Of a country so large as the United States no adequate physiographic description can be given within the limits of a monograph of this size. The purpose here is to define the great slopes, and then a greater number of physiographic regions, which are again divided into districts, and to indicate some of their more important characteristics. Three of the regions have been selected for a somewhat more elaborate description,—one of plains, one of plateaus, and one of mountains,—thus illustrating briefly all three types. These regions are the Atlantic Plains, the Colorado Plateaus, and the Pacific Mountains, taking the eastern, a midland, and the western region.

It will be noticed that an old custom of describing great physiographic regions in units of basins has not been followed. Against that plan there are insuperable objections. Where there are large rivers, there are large basins, and such are again subdivided into ever smaller and smaller basins; and where there are oceans and gulfs, there are many small disconnected basins; so that the basin unit divides the country into very unequal parts, and fails to exhibit the association of great features that are intimately connected in physiographic history. Gradually, as the new science of physiography has grown, physiographic regions have come to be recognized; and an attempt is here made, by map and verbal description, to define the principal regions of the United States, exclusive of Alaska.

The regions here delineated are held to be natural divisions, because in every case the several parts are involved in a common history by which the present physiographic features have

been developed. They have been characterized by the more prominent features used in the name.

In dividing the United States into a few great physiographic regions, it is not found possible always to draw the lines with exactness. Often one region blends with another, the transformation in general characteristics being marked by a general change. There are some lines of division clearly drawn by nature within narrow limits; other divisions are imperfectly marked by slow gradation from one to the other.

DRAINAGE SLOPES.

The United States may be divided into four great slopes,—the *Atlantic*, *Great Lake*, *Gulf*, and *Pacific*. All the streams of the Atlantic slope drain into that ocean by river mouths within our territory. All the streams of the Great Lake slope ultimately discharge into St. Lawrence River within our own territory. To the north another region not within our domain is drained into that river, which ultimately discharges into the Atlantic Ocean. This larger division is therefore but partly included within the United States. The Gulf slope includes all of our territory drained into the Gulf of Mexico. In popular usage, most of this is called the valley of the Mississippi, while small areas are drained into the Gulf by streams not tributary to the great river; and in the southwest there is a district drained by the Rio Grande del Norte, which heads in central Colorado, flows through New Mexico, and then turns eastward, forming the boundary line between the United States and the Republic of Mexico, until it discharges into the Gulf. Its waters only in part are caught on the soil of the United States: it is a very small part which comes from Mexico. Along the western border of this grand division the country is arid, having a rainfall of less than twenty inches annually. In this arid region there are many small streams whose waters are not carried away by ocean-feeding rivers, as the small streams are lost in the sands.

On the Pacific slope all streams that ultimately run to the sea reach the Pacific Ocean mainly within the territory of the United States; but the district drained by the Colorado River of the West reaches the Gulf of California by passing a short distance through Mexican territory. In a large part of the Pacific slope there are many small streams that discharge their

waters into sands, where they are evaporated and lost from the ocean-reaching drainage; but the valleys in which they are evaporated incline toward streams draining into the Pacific Ocean.

We thus have an *Atlantic* slope, a *Great Lake* slope, a *Gulf* slope, and a *Pacific* slope; and these terms are coming into common use for the four grand divisions of the United States.

An examination of the relief map of the United States published by the general government will show that the lines of separation between these great slopes are very irregular. Everywhere along them there is an interosculation of head-water streams. Between the Atlantic slope and the Great Lake slope the divides are sometimes in mountains and sometimes in hills; between the Atlantic slope and the Gulf slope the meandering division line is in part in mountains and in part along the low peninsula of Florida; between the Gulf slope and the Great Lake slope the dividing line is an inconspicuous elevation, so low in many places that the waters may easily be diverted from one slope to another; and in late geologic time this change has often occurred, and a part of the drainage of the Great Lakes has been turned from the St. Lawrence into the Mississippi. The irregular divide between the Mississippi region and the Pacific region is sometimes mountainous, with peaks varying from eight thousand to fourteen thousand feet above the level of the sea. The Atlantic slope is a comparatively uniform declivity, relieved by plateaus, mountains, and hills that do not rise to great altitudes above the base-levels of the streams. With slight exception, the Great Lake slope is a vast plain broken into subordinate plains by terraces and hills. The Mississippi slope has the Appalachian Mountains on the east, with declivities for its streams that greatly decrease from the mountains to the river, and is relieved by plateaus, hills, and mountains with great altitudes above the rivers near the Appalachian and Rocky mountains, and has low reliefs nearer the Mississippi. On the north the line of separation from the Great Lake slope is in a single plain, but without perfect uniformity, for there are many terraces and hills. On the west the rim of the basin is in high mountains with lofty peaks, and all along its western border the reliefs are of comparatively great magnitude.

The Pacific slope is in the great Rocky Mountain region. The Stony Mountains stand on its eastern border at the north, separating it from the Missouri drainage. Here towering moun-

tains with a wilderness of crags and peaks appear, over which the snows are mantled for many months of the year, and in whose deep gorges lie perennial snows. Then the dividing line extends between the Platte Plateaus, drained by Laramie River, and the upper extension of the Colorado Plateaus, drained by Green River. The divide is in the Park Mountains, characterized by great peaks, and extends still farther southward across the Colorado Plateaus, and down the Basin Ranges to the Mexican line. On the flanks of the Stony and Park mountains there are many volcanic peaks whose fires are now extinguished; still farther westward there are great plateaus and mesas carrying dead volcanoes on their backs; and still farther westward there are many ranges of mountains, generally extending in a northerly and southerly direction, between which lie great valleys that are often desert plains. Then we reach the Sierra Nevada at the south, and the Cascade Mountains at the north, which end the longitudinal ranges and valleys. The Cascade Mountains are mainly volcanic peaks standing on huge diastrophic plateaus, while the Sierra Nevada is a great complex diastrophic plateau carved into transverse ridges by streams that head on its eastern margin and run westward into the valley of California. The ridges between these east-and-west streams are very irregular, and decline in altitude from the east toward the west. In the Cascade Mountains the streams also have a general westward direction into the great Sound Valley; but there is a region which separates the Sound Valley from the valley of California, known as the Klamath Mountains, through which the streams heading in the southern part of the Cascade region and the northern part of the Sierra region flow to the sea without turning into the rivers of the great valleys. The Sound Valley within the United States is only a portion of a great valley which lies partly within British territory. North of Columbia River and west of Sound Valley stand the Olympic Mountains, and south of that river stand the Oregon coast ranges, sometimes called the Oregon Ranges. Thus the Pacific coast is exceedingly complex in its great topographic features.

These four grand divisions present interesting characteristics and contrasts, due chiefly to inequalities of rainfall, which produce *deserts*, *prairies*, and *forests*.

Deserts.—Plants require great quantities of water for their nourishment. With their roots they drink the water, and

through their leaves they evaporate it to the heavens. In this process a very small proportion is used by the plant, and built into its tissue. To grow a ton of hay, the grass plants must drink two or three hundred tons of water. The growth of vegetation depends very largely upon the regularity with which the roots of the plants are supplied with drink. When the rainfall is slight and periods of drought are great, vegetation is scanty; but when the rainfall is abundant, vegetation is more luxuriant. Temperature is another factor in the rate of growth. With high temperature and great rainfall, the most vigorous vegetation is produced; with low temperature and slight rainfall, more scanty vegetation is found; but if the rainfall is very small, high temperature serves rather to increase aridity and the desert condition. In the temperate zone, if the rainfall is less than ten inches annually, the desert conditions prevail; but, though the rainfall may be less than five inches annually, the desert will yet afford some classes of plants, like the agave, yucca, and cactus.

Many desert plants are covered with a kind of bark, the pores of which close in times of aridity so as to prevent their water from being evaporated. Other plants have a habit of rolling up their leaves and folding their stems in such a manner as to present the smallest surface for evaporation. Nearly all desert plants are furnished with thorns, and many with acrid juices that protect them from being devoured by animals. So the plants struggle for existence. The animals of the desert are few, though some insects and some reptiles abound; and among them many curious forms may be observed.

Deserts are beset with dunes formed of wind-blown sand. Sometimes deserts have scattered over their floors pebbles, which are the remnants of formations carried away by degradation. They are worn fragments of very hard rocks, often crystalline and of many colors. As the sand sweeps over them, the pebbles are polished, and the desert is sometimes floored with a mosaic of brilliant gems.

Prairies and Forests.—As the rainfall increases from ten to twenty inches, grasses and various other plants are multiplied, and become more and more luxuriant; and low, gnarled trees, especially cedars and pines, are developed, if they are protected from fires. As the rainfall increases from twenty to forty inches, forests increase; that is, they are extended over greater areas, and the trees themselves have a more rapid growth, and attain

larger size. In such regions vigorous forests will grow, if they are protected from fire. The great prairie region of the United States is found mainly where rainfall is from twenty to forty inches, because the forests are destroyed by fire. Going from the more arid to the more humid regions, forests become more frequent and more vigorous; and especially are trees found near streams, and where the lands are hilly, broken, and stony, so that luxuriant grasses are not abundant, to furnish food for fire.

Since the prairies of the United States were settled, great changes have been wrought in the landscape. Protected from fire by the plowman's furrow, trees have sprung up everywhere; so that to-day, through all that region stretching from the Ohio across the Mississippi and across the Missouri on to the Great Plains, the forest areas are rapidly multiplying, and planted groves are common. It is thus that cultivation protects forests, and furnishes the condition for foresting lands which were prairies in their primeval state.

When man attempts to preserve large forests without protecting the ground with the plow or by other agencies, he usually fails. To save the forests, he carefully tries to prevent fires; then grass, leaves, bark, twigs, and boughs gather upon the surface of the earth from year to year, until a thick coating of inflammable material is formed. Immunity from fire thus furnishes food for fire; and when a dry season comes, an accidental spark starts a great conflagration, which spreads with the wind as only "wildfire" spreads, and the great accumulation of combustible material makes a sweeping flame which destroys everything before it. It is thus that the forests of the Northwest, which are largely held for lumber purposes, are subject to fires that destroy property on a great scale, and even destroy human life.

Where the rainfall is sufficient protection, and fires are not kindled, forests prevail. In southern latitudes and low altitudes the trees attain a greater size than in northern latitudes and high elevations; but there are some important exceptions to this general rule. In Washington, Oregon, and California, gigantic forests are found developed by humid lands that lie near the Pacific coast, while other groves of great trees stand on the slopes of the Sierras that face the great ocean. Where the moisture is more than fifty inches, and where other climatic conditions are favorable, dense forests of gigantic trees, with tangled masses of undergrowth, stretch over the land. In the great

valley of California, live-oak groves abound, and the trees are gnarled and picturesque. In more arid lands, groves of low, spreading, gnarled piñons and cedars are scattered at wide intervals. In early time, before the prairie region was settled, there were found groves of low, spreading bur-oaks, that from a distance looked like orchards; and in fact they were orchards of acorns. In the humid lands, and especially in the tropic lands of Florida, the great trees are often draped with festoons of "Spanish moss," and decorated with beautiful orchids. In the valley of the Ohio, magnolias spread their blossoms as goblets of perfume. All over the Alleghany Plateaus, the Appalachian Mountains, and the Piedmont Plateaus, great tulip trees stand, with stately boles and light branches that bear most beautiful flowers. In every flood plain of the United States, sycamores with smooth trunks, broad arms, and expanding leaves, spread a sweet shade over the ground when the summer sun is fierce. By every river, creek, and brook the willows stand, and dip their delicate leaves into the murmuring waters. In the ponds and lakes of the United States, water lilies grow, and on all the hill-sides roses bloom. Late in the summer the goldenrod bursts into flame along the northern border of our land; and as the weeks and months pass, the zone of gold sweeps southward until it is stopped by the Gulf.

Before the settlement of America by the Europeans, while the land was yet under the sway of savage tribes, the whole country was annually burned over, and wherever forests could be destroyed they were swept away; but when the lands were plowed, the fires were stopped; and vast regions that were prairies at that time are now forest-clad. To-day the forests of the United States are somewhat more extensive than they were at the landing of Columbus. While the prevention of fires saves some trees, the ax fells others, so that many forest regions have been transformed into fields; yet to-day fires destroy more trees than the ax.

The growth of trees depends upon rainfall, but partly also upon care. Seeing that arid lands are treeless, many observers reach the conclusion that aridity is due to the destruction of the forests. The effect is mistaken for the cause. This superstition has widely prevailed, and many of those who have not studied this subject believe that rainfall can be increased by the planting of trees. This subject has been most carefully and thoroughly

investigated by scientific men, and they are not able to discover that the presence or absence of trees either increases or diminishes the rainfall; and yet this myth is told all over the land.

On the Atlantic slope primeval forests were discovered in the early settlement of the country, and a few of the valleys were prairies. Forests were mainly open, without dense undergrowth, as they were annually burned by the Indians. Since the settlement of the country, great areas have been cleared, and prairies have been brought under the plow. The forest lands that remain have been protected from fires, the undergrowth is preserved, and open forests are no longer seen. Here the forest area is smaller than at the advent of the white man, but the number of trees is nearly as great.

The Great Lake region also was mainly covered with forests when the country was settled by civilized people; but the groves were open, and the trees were comparatively low and gnarled, as they were often singed by fires. The primeval forests are nearly gone, much of the country is under the plow, but the new forests present changed characteristics. The new trees, densely crowded, compete for the light of the sun, and grow to greater heights; and the ground below is covered with dense foliage and tangled undergrowth. Here also the forest area has been reduced, but the number of standing trees is perhaps as great as in primeval times.

The greatest change has been wrought in the Mississippi slope. Its northern and central portions were mainly a prairie region, and extended to the foot of the Rocky Mountains. The few forests to the north, the greater wooded regions on the flanks of the Appalachian Mountains, and the more imposing forests on the south, protected from fires, have increased in the number of standing trees, though great fields have been cleared for agriculture. Throughout the prairie region the river-border groves have become more dense, and the trees more stately. From these groves the native forests have spread over a large aggregate of ground, and many groves and orchards have been planted. Though this prairie region is densely settled and much of it cultivated, the groves have lost their primeval character, and the vigorous trees have multiplied to an astonishing degree.

The Pacific slope presents great contrasts in its southern part, where there are extensive areas of desert. The mountains and high plateaus are everywhere covered with forests; and on

the slope of the Sierras groves of giant sequoias are found, while near the coast towering redwoods appear. In western Oregon and Washington, yellow pines, redwoods, and cedars, and many other stately trees, flourish in the warm, humid lands that are supplied with moisture from the Pacific. On the Pacific slopes we have dreary deserts, prairie valleys, and gigantic forests.

THE ATLANTIC PLAINS.

A monoclinal flexure extends from the Jersey side of Hudson River near the city of New York, southwestward past Trenton, Philadelphia, Baltimore, near the falls of the Potomac, above the city of Washington, where the line curves in a more southerly direction to Richmond, Weldon, Raleigh; and turning westward, it crosses Savannah River near Augusta, and gradually disappears in the region of Macon, Ga. This geologic feature extends in an indefinite way past Montgomery. It is easily followed by the geologist from New York to Macon, past the streams that flow into the Atlantic, until streams are reached which fall into the Gulf of Mexico. This line of displacement has an interesting geologic history. The rocks to the west and northwest are of Archæan age; the rocks to the east and southwest are mainly of Cretaceous, Eocene, and Neocene age. The line or narrow zone separates hard, dark, crystalline schists, traversed by veins of white quartz that are of ancient geologic formation, from gravels, sandstones, shales, and clays, that make up the rocks of later origin. Since the beginning of Cretaceous time, a zone extending from the monoclinal flexure to the sea has passed through several vicissitudes of history, at times being dry land as it is now, and at times being sea bottom. So the shore of the sea has oscillated slowly back and forth across this part of the Atlantic Plain. Along the advancing and receding coast, gravels have been piled by streams coming from the landward side, and with them sands and clays have been deposited; but the finer materials have always been carried farther into the sea, and the coarser materials left near the shore. In studying the rocks of which the plain is composed, as they are exposed in stream banks and bluffs, and as they are revealed in digging and boring wells, alternations of gravel, sand, and clay are discovered; and the gravels usually increase in thickness toward the northwest, and thus appear to be shore deposits along an advancing or re-

ceding coast. Distinguished so clearly by geologic features, the topographic characteristics of this zone are even more plainly marked. The line of flexure is everywhere more or less clearly defined as a terrace broken by valleys and stream channels. In the streams the line is still more marked, for everywhere they cross it in rapids and falls. Far above there are rather swift-flowing but quiet reaches; at the flexure they plunge down with rolling, turbulent currents, and fall into broad channels with placid waters. Below, all the streams of magnitude rise and fall with the tides; above, all the streams rise and fall with the great storms; while along the narrow zone of flexure the clear waters are transformed into rushing torrents by long-continued rains. Here we find the great water powers which have been utilized ever since the early settlement of the country; and here we find the barrier to navigation, for the vessels that come from the Atlantic coast cannot be navigated across the fall line, and all boat transportation from below ends here. A few of the streams can be navigated above this line; but their cargoes must be carried over the fall line and reshipped, to reach the streams below. The zone of displacement is thus marked by characteristics which divide the country above from the country below in a double way. It is the zone of water powers and the zone of interrupted transportation by water. Under these circumstances the fall line was well marked in primeval times, ere yet the white man had settled in the land, for a line of Indian villages extended along it from the Hudson to the Savannah. Later, under the ægis of civilization, cities were built at this line, with convenient water power for manufacturing purposes, and easy means of commerce with the old country by the sea, and with the interior by rivers, canals, and roads. Thus, unconsciously to the savage and unconsciously to civilized man, geologic conditions fixed the sites of ancient villages and modern cities at the head of tide water and in the region of the great water powers. From this fall line a great plain extends to the coast, marked by few hills, and slightly terraced with bluffs on the margins of flood plains. Near the coast and along the flood plains extensive marshes are found. This irregular zone of marsh is clearly distinguished from the higher plain. A lower plain extends from the coastal marshes out to the sea for many miles, until at last shallow waters change into deep waters, and the bottom plunges down with steep declivity into the depths of the Atlantic. This

Atlantic plain is therefore naturally divided into three great zones,—the *subaërial* portion; the *marsh* portion, which is covered more or less intermittently with water by tides and storms; and the *submarine* portion, which extends out to deep waters.

Above the city of New York the marine portion of the plain expands, while the marsh portion is usually narrow, though sometimes it extends back into the high land many miles; but it is often broken, when higher lands extend down to the tide, and the submarine plain is separated from the subaërial plain only by sea cliffs. In this northern region the land portion of the plain is very irregular: in some places it is narrow, in other places it expands to considerable width, but altogether it is much less conspicuous than it is below the Hudson. South of Macon, Ga., there is an irregular line of parting between the waters of the Atlantic and the waters of the great Gulf. That portion which drains into the Atlantic is still called the Atlantic Plain, and it thus embraces a part of Florida down to the Keys. Off southern Florida the submarine portion is greatly narrowed, while the marsh portion expands into the great marshes of Florida, which extend from the ocean to the Gulf.

The land plain is usually rich agricultural land, and is extensively cultivated. The marsh plain has a wealth of deep soil, and wherever redeemed by drainage or embankments it yields bountiful returns to agricultural labor. The sea plain is the site of a coastal commerce which has already attained great magnitude, and which is steadily growing. The scenery is monotonous in relief, but wonderfully varied with bays and gulfs, and broad, quiet rivers, the banks of which are diversified with stately groves. From the palmetto of the South, to the low, gnarled oaks of the North, there is a panorama of ever-changing forests. At the South, coral groves abound, which unite with sediments from the land to build fringing islands. Northward from the coral homes great rivers loaded with sediment supply sands that are deposited by the currents, and by the waves are built into other fringing islands all along the marine plain until we reach the great sand banks of the North. In a few places there are diastrophic islands, and behind them there are great harbors, as in New York Bay. Especially along the coast of New England there are many diastrophic islands, and from New York to Boston they protect quiet sounds that are utilized by commerce in great fleets, whose white sails skim the sounds all summer long.

Along the coast of Maine the tides sometimes rush up the rivers in great bores, and the rock-bound coast is protected by sea cliffs. On this beautiful Atlantic coast the traveler may sail from coral reefs to seas where icebergs float, and may return by the steel highway from cranberry gardens to orange groves.

THE PIEDMONT PLATEAUS.

The Piedmont Plateaus lie west and northwest of the central portion of the great Atlantic Plains. The rocks of which they are composed are mainly of Archæan age, and are all more or less metamorphic. Often they are of slaty structure; that is, the sedimentary beds originally laid down in strata have, by diastrophism, compression, and chemical change, become metamorphosed; ofttimes the old stratified structure has been destroyed and a new structure imposed upon the rocks, so that they appear in thin plates which do not conform to the old stratified planes. This structure, given by metamorphism, is known as *slaty* structure. Besides the original sedimentary beds, primarily there were great bodies of lavas, and these also have been metamorphosed. During Cretaceous time, while the Atlantic plains to the eastward were sometimes land plains and sometimes submarine plains, and while the coast line was shifting back and forth, the Piedmont region was degraded to a great system of plains which were traversed by streams running to the sea. The whole plain seems not to have been brought down to the level of the sea, but to have inclined slightly to seaward and toward the valleys of the streams; so that, in referring to its plain condition, the region is often called a *peneplain*. When the land portions of the Atlantic Plain were finally unmasked by the upheaval of the land and the retreat of the sea, the same system of upheaval extended throughout the Piedmont region, and has continued with intermission to the present time, until the old plains have now reached an altitude which constitutes them plateaus, as that term is now defined. We have already shown that the Piedmont region is narrowly defined on the Atlantic side by the fall line, which separates it from the plains. On the northwestern side it is bounded by the Appalachian Mountains. The line of separation between these two regions is not always as clearly defined as that on the other side, and yet in the main it is distinct.

The region had a great extension of plains, sometimes diversified with many hills, before its upheaval into the plateau condition. In various places there were areas of quartzite which were hard and unyielding to degradation, and which remained as hills. In other regions there were bodies of firm granite, probably of volcanic origin, which also resisted degradation and remained as hills. Over the old plain surface these ancient hills still remain to crown the plateaus. As the upheaval began, the plain was tilted eastward, and the sluggish streams were urged to greater activity, until they became swiftly rolling rivers and creeks, and even the brooks danced in joy with the new activity. With this new-born life they began to corrade their channels and to cut them in deep gorges, and gradually they carved out valleys, and divided the old plain into plateaus separated by luxuriant valleys with meandering stream channels and flood plains; while the hills on either side ascended to ancient plains, now plateau summits with their embossed hills. As corrasion presses hard upon upheaval, channels are cut more rapidly than the general surface is disintegrated and washed away, and for this reason the lateral stream gorges and valleys have a slightly convex profile; but when upheaval ceases, convex profiles are slowly changed to concave profiles. By this characteristic geologists often discover important time relations between diastrophism and degradation. From these characteristics of convexity and concavity, and from certain related facts, it is known that the Piedmont Plain was not upheaved evenly and simultaneously in all its parts, but that it was lifted now at one place and now at another. Where first lifted, the gorges and valleys are convex; where last lifted, they have concave profiles. There is not space here to characterize fully the Piedmont region in this respect, but reference will be made to one of the districts which has been uplifted in very late geologic times.

The Susquehanna River, which debouches into the head of Chesapeake Bay, is well marked by rapids at the fall line near its mouth; but above, swift waters continue, crossing the Piedmont Plateaus up into the mountain region. In late geologic time, tide water extended through this reach of the river in a broad, shallow channel which carried fresh water from above. By the last upheaval and tilting in this stretch from the fall line into the mountains, the flow of the river was accelerated, and the swift waters have mainly swept away sediments that

had accumulated on the bottom of the channel and along the old flood plain. Yet this upheaval was late, and may be yet in progress; so that sufficient time has not elapsed to carve a new channel in the old rocks below, but only enough to carry away the greater part of the soft materials,—the ooze and sediments that gather on the bottom of the old broad-cut river. The old bottom of hard rocks was very irregular as a floor; and as the soft rocks have been carried away, this irregular surface appears. Many channels in the hard rocks have been cut, and the irregularity is now even greater than it was originally. For this reason the Susquehanna falls into a very broad, shallow channel, beset with great bowlders and bordering ledges of rock; and it often runs in many channels, while patches of sediments that lined the old river bottom still remain here and there. It is thus that history is recorded in river channels, graved in glyphs by corrading streams.

Many fissures in the metamorphic rocks of the Piedmont Plateaus have been filled by the deposition of white quartz once held in solution in the underground waters. In this manner extensive veins of the white crystalline mineral ramify through the rocks, which are usually dark and somber, but are enlivened with the veins of crystalline quartz. In these veins minute fragments of gold are discovered throughout the Piedmont region. Ever the shining metal has attracted the eye of civilized man, and gold mining has been extensively practiced; but the quantity found has never been very great, and usually the quartz veins have failed to remunerate labor.

THE APPALACHIAN RANGES.

These ranges extend from southern New York into the State of Georgia. On the southeast the Piedmont Plateaus stretch from the foothills of the mountains. On the northwest the great Alleghany Plateaus lie, joining the Lake Plains in the region of the Great Lakes, and the Prairie Plains in the region of Ohio River. These mountain ranges are composed mainly of ridges whose longitudinal direction is from the northeast to the southwest. Between these ridges valleys are found. Usually a valley separates the mountain region from the Alleghany Plateaus. This system of mountains is naturally divided into two parts, the northern Appalachian and southern Appalachian

ranges. On the north the streams heading in the Alleghany Plateaus run southeastward into the Atlantic Ocean, and cut through the ranges by great gorges that are popularly called *water gaps;* but south of New River the Appalachian Ranges are drained into the Gulf. The streams head in the crest of the most eastern range, and cut through the ranges to the west by flaring gorges, and most of them empty into Ohio River by the waters of Cumberland and Tennessee rivers. In early Cretaceous and Juratrias time the Appalachian Mountain and the Alleghany Plateau regions were reduced nearly to a base-level. In Cretaceous time these regions were again lifted by diastrophic agencies. The northern plateaus were tilted in a manner which turned their waters toward the Atlantic, while the southern plateaus were lifted in such a manner that their waters were turned toward the Ohio; so that now we find the Delaware, the Susquehanna, and the Potomac rising far to the northwest in the Alleghany Plateaus, and flowing southeast across the Appalachian Ranges to the Atlantic, while New River and the tributaries of the Tennessee rise far to the southeast in the Blue Ridge, and flow northwest across the Appalachian Ranges and the plateaus beyond to the Ohio. The two portions were further differentiated by reason of a great distinction between the methods of interior diastrophism. The folding of the northern Appalachian Mountain belt was more regular in great anticlinal and synclinal flexures, while in the upheaval of the southern mountains the folds were crowded together and often faulted on a gigantic scale. These ancient folds were planed down when the whole region was brought nearly to a base-level, and the new valleys cut on the later upheaval were carved mainly in soft rocks, while the mountains that are left are composed mainly of hard rocks. The valleys, therefore, do not follow downturned flexures, but lie along out-cropping edges of hard beds, while the streams themselves from time to time cut through the ranges by flaring gaps. In the same manner in the southern mountains, hard rocks make mountains, and soft rocks produce valleys; but these valleys are less regular below, because of the great lateral thrusts by which the strata were closely plicated and often faulted. Usually the valley between the mountains and the Alleghany Plateaus is wider, and is a more conspicuous feature, than the other interrange valleys. The ridges themselves are rather monotonous mountains, but in the water gaps picturesque scenery is found.

The valleys that are regular and beautiful are highly cultivated and densely populated.

ALLEGHANY PLATEAUS.

In a broad way these plateaus are carved out of a great block of sedimentary rock tilted to the northwest from the Appalachian Mountains down to the Prairie and Lake plains. In Cretaceous and Juratrias time the block was graded to a plain, the surface of which generally conformed to the stratification. The great block is slightly warped, and there are many local evidences of minor diastrophism. In general the plateaus are crossed by deep, comparatively narrow water channels. As the streams run in deep channels, all the larger ones being in gorges from two hundred to a thousand feet in depth, the dissection of the plateau block is often minute, and many plateaus are thus formed. The region of the Piedmont Plateaus, Appalachian Mountains, and Alleghany Plateaus, in its earlier geologic history, extended farther to the northeast, and gradually faded out; but its structure is still preserved, though more or less masked by glaciation. It is even to be observed in the Green Mountains of Vermont, as well as in the Berkshire Hills of Massachusetts, which constitute a part of the Green Mountains. But north of the Piedmont Plateaus the region has been carved by glaciation and masked by glacial hills, so that it is best described by itself.

NEW ENGLAND PLATEAUS.

In this and the two preceding monographs mention has been made of the action of glaciers in grading the land, but the subject did not receive adequate treatment for want of space. Yet in characterizing the physiographic regions of the United States it becomes necessary to say something more of the action of ice, and of the history of a time known as the glacial period.

The most of Greenland is now covered by ice. Ice is found over great areas of the northern extremity of this continent and far down the Pacific coast. At different times in the Pleistocene period this ice capping of the land reached much farther southward. There was one great body of ice, known as the Laurentide Glacier, which extended over Canada and other parts of British America down into the United States, its most extreme

lobe reaching to a point in the Mississippi Valley not far from the mouth of the Ohio. Geologists have shown that it covered an area of about three million square miles. There were other great glaciers farther west which we need not here consider.

The Laurentide Glacier endured for a long time, and passed through many phases of history. Perhaps it existed at two or three different times, with intervening periods of milder climate, when it was melted. In its greatest development it must have accumulated to a thickness of hundreds or thousands of feet. Its different portions were ever moving on the surface of the land, and grinding up the rocks below, and pushing them down the slopes in a general way to the southward, with many variations. The rains fell upon this glacier through the centuries, and the sun melted the ice, and the water percolated to the surface of the ground, and flowed away in subglacial streams that carried with them the rock-flour ground by the ice, which was armed with rocks carried along by the ice. It is thus that the great glacier served as a mighty agency for the degradation of the land, pushing the bowlders and ground material along its bottom, and carrying it away in channels, often piling it up in moraines, drumlins, kames, eskars, and other forms, and spreading the finer materials in great sheets of clay and fine sand.

A portion of the Laurentide Glacier was expanded over New England and New York down to the very site of the great city. Over this region it extended for a long time, though its existence may have been intermittent; but it remained long enough to accumulate masses of ice with power to perform the stupendous task of refashioning the surface of the land. It found mountains, plateaus, plains, valleys, and hills, but it changed them all by carving new forms to its own liking; but, more than all, it built a vast army of hills, and filled many valleys. The modified mountains yet remain; the old plateaus, though changed, still stand; but the valleys and hills are to a large extent new features. I have called this region the New England Plateaus because before the advent of the ice it was a great group of plateaus diversified with mountains, hills, and valleys. Now new hills are found widely scattered over it, sometimes in its valleys, always over its plateaus and over the flanks of its mountains. The Adirondacks still stand, much modified by glaciation. Down Vermont the Green Mountains extend into the State of Massachusetts, where they are called the Berkshire Hills. Everywhere they have been

remodeled by ice. Still to the east, in New Hampshire, are the White Mountains, with Mount Washington as a culminating peak; and there are lone mountains scattered over Maine, and the region extends beyond our boundary into British territory.

The structure of these plateaus is more or less masked by glacial hills, and there are great valleys with river plains exhibiting fragments of ancient glacial hills. Near the Atlantic the coastal plain is broken, and many sea cliffs are found, and the coastal marshes are very irregular. In New York, glacial valleys and more recently cut river valleys are found, and limited plains are seen, especially in the region of the Finger Lakes. Scattered through the region are many lakes of clear, cold, beautiful waters; and there are many marshes, some fed by the tide with salt water, but many more with fresh water; and the interior lakes are mainly of glacial origin.

LAKE PLAINS.

In the northern portion of the United States there is a lake region which extends still northward far into British America. In the midst of the region lie the Great Lakes, — Ontario, Erie, Huron, Michigan, and Superior; and about them, to north, south, east, and west, many others are found of less magnitude, to the number of thousands. The region is in large part drained by the St. Lawrence, and in small part by the Mississippi. The Great Lakes are primarily of diastrophic origin, but they have all been remodeled by ice, while the smaller lakes are due mainly to glaciation. The great Laurentide Glacier extended over all this region, and buried it deeply under the ice, and during its history made great changes in the land surface by degrading old forms, and building new lands.

Previous to the advent of the glacial age, the region was in the main a system of great plains, with hills and some minor plateaus; but when the ice came, it covered them all, and wrought a regeneration, leaving the Great Lakes still lying in their diastrophic basins, but adding to the region a vast assemblage of glacial lakes, many of which remain, while many have been filled with peat, and drained by new stream channels. The plains left by the glacier were low, with comparatively little relief.

Since the disappearance of the ice sheet, diastrophism has progressed as of old; so that the Lake Plains have been warped,

and it becomes easy to identify these diastrophic changes. As it is a region of many lakes, and as the streams have all been corrading new channels since the disappearance of the ice, the great and small lakes have often been terraced. The greater plains have in this manner been cut into small lake plains that are low stairways from shores to high lands. Thus the region is characterized by great plains base-leveled in earlier geologic periods, releveled during the glacial period, and terraced with lake plains since that time. By reason of its many lakes and its numerous terraces, it is well characterized as the region of Lake Plains. Four districts may be recognized, as shown on the map.

PRAIRIE PLAINS.

On the south and on the west of the Lake Plains stretch the great Prairie Plains. When this region was first visited by white men, much of it was destitute of forests. In the east, glades and small prairies existed; farther westward the prairies became larger, until, in eastern Indiana, the prairie region prevailed in extent over the forest region, while beyond the Mississippi the prairies were interrupted only by the groves that border the streams. This prairie region sweeps around the great Ozark Hills, and extends southward nearly to the Rio Grande del Norte. Here and there it is relieved by low hills, and it is cut with a labyrinth of stream channels, on the borders of which flood plains appear that were usually covered with trees in the olden time. The Laurentide Glacier extended across this prairie region down nearly to the mouth of the Ohio; and wherever it was spread, great glacial accumulations appear as beds of clay, sand, and gravel, and sometimes as glacial hills. On the last retreat of the ice there were left behind many little basins, into which the waters were gathered; and a multitude of little lakes were thus formed, many of which were gradually drained by the streams, and filled with peat. It is thus a region of small extinct lakes, whose shores were rarely terraced because of the brief life awarded to these little bodies of water.

On the west the prairies merge imperceptibly into the region popularly known as the "Great Plains," but which we now call the Great Plateaus, for the reason hereafter to appear.

The lands of the prairies are fertile. Douglas Jerrold said, that, if you tickle them with a plow, they will laugh with a har-

vest. When the country was first settled, the districts far away from standing timber were supposed to be almost uninhabitable for the want of fuel and timber; but under the prairies vast coal fields have been found, and the men of the prairies have learned to fence with hedges and iron wires, and they have built railroads, on which they have carried the lumber necessary for their homes. The agricultural industries of all that land have flourished. Gradually the lowlands have been drained and tilled and the higher lands have been plowed, forest groves have been planted and the old woods have spread, thousands of orchards have been grown and vineyards have been planted and gardens cultivated, until a greater proportion of the land has been brought under the plow than that of any other region of the world of the same magnitude. Two districts are shown on the map,—the one glaciated, and the other not.

THE GULF PLAINS.

On either side of the Mississippi River, from a little above the mouth of the Ohio, a great plain stretches to the south, and expands to the Gulf waters. On the east the border of this plain skirts the Alleghany Plateau and the point of the Piedmont Plateau, and extends east to the line of parting waters between the Atlantic and Gulf drainage, which it follows into the marshes of lower Florida. On the west it flanks the foot of the Ozark Mountains, and continues southwestward to the Rio Grande del Norte. All of this area we call the Gulf Plains. Down its middle the Mississippi runs, and along the Mississippi and up its important tributaries there is a great flood plain. Thus the Gulf Plains are divided into five great districts,—the East Gulf Plain, the West Gulf Plain, the Flood Plain of the Mississippi, the Coastal Marshes flooded by salt water from the Gulf itself and by fresh water from the land, and the Submerged Plains extending into the Gulf, so that there is a submarine portion, as on the Atlantic coast. Under the waters of the Gulf, far out at sea, the submarine plain is ended by a comparatively abrupt declivity, where the Gulf bottom drops off from shallow into deep waters.

The Mississippi Flood Plain starts at the foot of the great glacial deposits in Illinois, and at the Gulf end it expands into a great delta built into the Gulf by sediments brought down by the mighty river. This flood plain is usually well marked around

its outlines by high bluffs of *loess*. During glacial time the Gulf coastal plain seems to have been somewhat more depressed than at present, and the water of the glacier gathered into a great basin which emptied into the Gulf. In this basin the rock-flour ground by the mealing stones of vast glaciers was deposited as an exceedingly fine sediment. When the Laurentide Glacier was melting away into fragments in the far north, the land rose again a little, and the Mississippi cut for itself a new channel, which was widened into a flood plain. The material into which the channel and the flood plain were cut was of glacial origin, and we call it *loess;* and thus the bluffs are of this formation. The Gulf region is rich with fields of corn, tobacco, and cotton.

In pre-Columbian times the entire region was a primeval forest of giant trees and dense undergrowth entangled with vines. Into these forests aboriginal tribes penetrated to fish in the waters, to hunt on the land, and to cultivate little garden patches in corn and squashes. Here they built mounds on which their homes were erected; here they buried their dead in mortuary mounds; and here they constructed great tumuli upon which stood their council chambers, and where their ceremonies were held. On these artificial hills they established their tribal homes; worshiped the sun, moon, and stars, and many animals; organized tribal governments of elaborate structure; and enforced laws that secured a high state of justice.

THE OZARK MOUNTAINS.

Extending southward and westward from the Iron Mountains of Missouri far into Arkansas, there is an elevation of land which we call the Ozark Mountains or Ozark region. This region has an interesting though complex history. It is properly divided into two districts. That north of Arkansas River has been a great plateau, and still retains many of the features of a plateau, but it is deeply trenched by numerous winding and complicated streams; and the reliefs or elevations which have been preserved have the structure of huge hills and small mountains, though a few of the forms are of more gigantic structure. Some of the greater elevations above the streams are in the Iron Mountain region, and others are called the Boston Mountains. The rocks are sometimes faulted, and the streams often follow fault lines. In the Boston Mountains the strata are chiefly hori-

zontal, and are deeply channeled. On the south the rocks of this region in a general way bend down in a synclinal fold, and reappear south of the river; below they are found strongly folded and sometimes faulted, and are eroded into long, parallel mountain ridges with intervening valleys. Going southward, the ridges have a general east-and-west trend, but are often curiously carved and faulted. In the most southern portion of the region the streams are transverse to the rock structure. It would be well to call the northern district the Ozark Plateaus, and the southern district the Ozark Ranges.

THE GREAT PLAINS (PLATEAUS).

The region popularly known as the "Great Plains" is in fact a great group of elevated plateaus. They have therefore been colored as plateaus, and grouped in districts which are called plateaus. It would serve to harmonize the nomenclature if the name could be changed from *plains* to *plateaus.* The zone in the United States extends from British America to the Rio Grande; and the region extends far northward in British America, and southward in the Republic of Mexico. Within the United States four districts are demarcated.

The Missouri district is deeply trenched by the upper Mississippi River and its great tributaries, in such a manner that the blocks to the north have their long axis extending from the northwest to the southeast, while the plateaus south of the river have their long axis extending from the southwest to the northeast. The principal streams of the region have their sources in the Stony Mountains, and carry large volumes of water, while the local tributaries are small. Along many of the smaller streams there are extensive areas minutely dissected by stormwater streams. The rocks are mainly soft shales, so that corrasion is rapid; and the hills thus formed in the easily carved shales are naked and desolate, and hence are called *bad lands.*

In the district to the south, called the Platte Plateaus, the rivers flow mainly in an easterly direction; and the trenches which they form divide the country into long table-lands having the same direction. The trenches are wider and shallower than in the north. The streams all join the Mississippi.

Going to the southward, the Arkansas Plateaus are found. The Arkansas, the Cimarron, and the two forks of Canadian

River, drain the entire district, and separate it into long east-and-west plateaus. The trenches of the rivers are not very deep, but are usually very wide, and their summits are great treeless plains. All these rivers join the Mississippi south of the Ohio.

The fourth district is drained mainly by the Pecos, having a southerly direction; but its eastern margin is drained by tributaries of Red, Brazos, Nueces, and Colorado rivers of Texas. This is the Staked Plains, the region best adapted to the study of the four great laws of corrasion, which may be stated as follows: —

First, other things being equal, the rate of corrasion progressively increases with the increase of the load which is the instrument of corrasion; *second*, other things being equal, vertical corrasion directly increases with the declivity of the stream; *third*, other things being equal, lateral corrasion increases inversely with the declivity of the stream, and vertical corrasion is transmuted into lateral corrasion; *fourth*, maximum corrasion is produced by maximum volume of water, maximum load, and minimum declivity, and the corrasion is lateral; *fifth*, a stream heading in mountains, and crossing arid lands, is supplied with a great amount of sediment by frequent winds and occasional hard rains, and is caused to spread in a wide channel, so that the depth of water is greatly diminished, while the sand, having but a short distance to fall, is driven along by short excursions: so that the rate of corrasion diminishes in inverse proportion to the depth of the stream.

THE STONY MOUNTAINS.

The Stony Mountains constitute a well-marked group drained by the head waters of the Missouri on the east, and the head waters of Snake and Columbia rivers on the west. The name "Stony Mountains" was first given to this group, but was afterward changed to "Rocky Mountains," and then extended indefinitely over other groups; but, as the group must be distinguished from others for physiographic purposes, it seems well to return to the original designation. These mountains appear to be of very diverse structure. There are a number of great ranges; but they are not very systematically grouped, and have different directions because they are complicated with vulcanic mountains, plateaus, and hills. Some are carved out of broad anticlinal folds, others are greatly faulted, and often sharp ridges

appear; but the geologic history of the country has not been so fully worked out that a consistent story of it can be given. The ranges are moderately high; and, by reason of the northern altitude and a fair amount of rainfall, they are covered for many months with snow, and here many beautiful streams have their origin. The flanks of the mountains and high plateaus are often covered with great forests, and the low foothills with gnarled trees. The valleys are rich and productive, though mainly treeless. Great mining industries are prosecuted, especially of gold and silver. In the heart of the group are the geysers and hot springs of the National Park, which has become a region of world-wide resort because of its wonders and its beauty.

THE PARK MOUNTAINS.

In southern Wyoming, central Colorado, and northern New Mexico a great group of mountains is found, whose lofty peaks are characterized by a wilderness of crags. The ranges are more irregular than those of the Stony Mountains, and have a general north-and-south trend. Between the ranges there are great valleys, which are known as *parks*. The four most important are the North, Middle, South, and San Luis parks; but there are others which almost vie with them in extent, and a great number of still smaller valleys, all of which are alike called parks. Above the timber line the peaks are naked; below, on the flanks of the mountains, great forests stand, and often spread over elevated plateaus; while the valleys are beautiful prairies or parks. The ranges having a north-and-south direction are carved out of great anticlinal folds, but in each fold a zone of maximum curve is usually discovered on either flank; so that the rocks at the flanks of the ranges are abruptly turned down, and extend under the parks, and are again turned abruptly above to a nearly horizontal position. Only fragments of these more horizontal beds above have been left: most of them have been degraded away. The central portions of the ranges are in the main composed of metamorphic rocks of great age. This more irregular structure is modified to some extent by faults and various minor wrinkles. On the flanks of the mountains and out in the parks there are many beds of vulcanic rocks, which serve still further to modify the aspect of the ranges. In a few cases, especially on the western side, these vulcanic beds

have been piled up in mountain forms. On the eastern side there are a few outlying peaks of volcanic origin. Notable among these are the Spanish Peaks. The group terminates to the south in the neighborhood of Santa Fe. The head waters of Platte, Arkansas, and Canadian rivers drain the mountains on the east; to the west they are drained by the head waters of Colorado River, which empties into the Gulf of California; while to the south they are drained by the Rio Grande del Norte. This is a land of ranges and valleys, of peaks and parks, of naked crags, forest-clad mountains, and plateaus.

There are features extending along the entire length of the group from north to south on the eastern side, and again irregularly on the western side, that give rise to many small and picturesque parks sometimes called *gardens*. It has already been explained that the rocks of later age are turned up sharply on the flanks of the mountains as sandstones, shales, and limestones of many colors, often of bright-red hues, while beds of alabaster are found. The rocks stand on edge. The softer beds are worn out, and the harder beds remain standing as great walls; so that many beautiful garden valleys are produced, parallel to the great ranges, and separating them from the plains below. The forms of these rocks are often varied and majestic, and sometimes fantastic. The Garden of the Gods, near Pike's Peak, is one of these valleys, which has become a favorite visiting place from the adjoining summer resorts.

COLUMBIA PLATEAUS.

To the west of the Stony Mountains stretches a great plateau region which is drained into the Pacific by tributaries of Columbia River. It is a complex of plateaus of diastrophic and vulcanic origin, relieved by a few great mountains, and having many beautiful valleys. The highlands are covered with forests; the lowlands are naked.

In Cretaceous time the region had many extensive plains, broad valleys, high mountains, and some portions were covered by the sea. The mountains were mainly of granite, quartzite, and mica schist, with rocks of later age on their flanks.

In Eocene time extensive diastrophism prevailed, and with it came vulcanic activity, by which a number of great mountain cones were erected.

In Neocene time the lavas were more fluid, and broke out in many new places, pouring out thin coulees, frequently filling or obstructing valleys. These later eruptions continued for a long time, upbuilding the region by burying the old topography and piling the lavas against the mountains. In the process, valleys were often dammed by floods of cooling lavas, and behind these obstructions many lakes were formed. Since vulcanism has ceased, many of these lakes have been drained, and the old lake beds are now rich agricultural lands. In many places the ancient mountain summits yet appear, but about them are scattered great irregular vulcanic plateaus. Small valleys have sometimes been carved, but often the streams have cut narrow trenches which are canyons. Frequently the canyon walls are composed of lavas, sometimes with interbedded lake beds. In the old mountain regions gold and silver are mined, and in many places the gravels left in the valleys and canyons below have much gold in nuggets, flakes, and dust, which gives rise to placer mining. Snake River runs for several hundreds of miles of its course through a canyon carved in the lavas. The walls of the canyon are often precipitous, effectually barring cross-river transit. In places late coulees have dammed the river; Shoshone Falls are formed in this manner. Here a mad torrent of water plunges over a great lava dam in a cataract of grandeur.

COLORADO PLATEAUS.

During the Cretaceous period a shallow sea spread over the region of the Colorado Plateaus. This great embayment of the ocean stretched far to the east, northeast, and southeast, and its oriental margin was a little east of where the Mississippi River now runs. In the midst of this sea there was a great archipelago where now the Park Mountains stand. In late Cretaceous and early Eocene time the entire sea was slowly upheaved, and the waters retreated. The upheaval was very irregular, and great diastrophic basins were formed, in which the fresh waters accumulated, and it thus became a great lake region. For a long time the waters were brackish, as the lakes evaporated to such an extent that only small channels were cut, such being sufficient to bear away the water not evaporated. In a broad way the upheaval in the eastern region was by gentle flexures; in the western region it was chiefly by faults. As the fresh-

water basins were many and large, and the land areas comparatively small, the dry lands were washed down into the Great Lakes; but elevation proceeded faster than degradation, and the lands grew both by upheaval and by the enlargement of their borders through deposition, or, as it is sometimes called, aggradation. The slow upheaval continued through Eocene time. The western half became highly differentiated from the eastern half, as at the west diastrophism was more energetic, and at the same time vulcanism was inaugurated on a great scale. In the plateau region, which we now have under consideration, the diastrophism was chiefly by faults and monoclinal flexures, and the whole country was broken into great irregular blocks, mainly by lines having a general east-and-west direction, but in the southeast a north-and-south direction. At the north the blocks were tilted to the north, but there were many minor variations, and in the south they were tilted to the east. The blocks thus produced are the great plateaus, which were modified and dissected by rains and rivers. At the time when these movements began, the rocks immediately beneath the sea were lying in a horizontal position to a depth of many thousands of feet. When the land was thus upheaved in tilted blocks, the strata were slightly inclined; and the streams heading in the blocks tilted northward mainly ran northward, with branches from the east and west, and for a long time were gathered into lakes that drained into Colorado River, while in the south they drained chiefly east and south into the Rio Grande del Norte. As general upheaval went on, all the lakes were drained by the cutting of outlet channels, and the whole region became arid. All this was in early Neocene time. At last, in late Neocene time, the diastrophic blocks were trenched; and when the lakes were drained, their bottoms became valleys, and the valleys were then slightly trenched by streams running into the Colorado and Rio Grande del Norte. Thus plateaus of great diastrophic blocks were dissected by a vast network of streams. The upturned edges of the blocks were degraded by sapping,—a process which was described in a former monograph,—and diastrophic cliffs were carried back in great steps or terraces. In this manner the plateaus were still further dissected, so that the whole region is now a vast assemblage of great plateaus, divided into smaller plateaus by the channels of streams, and still further divided by cliffs produced by sapping. In general the entire

region is a group of tilted blocks, whose higher edges terminate in great cliffs formed by sapping. There are a few cliffs which have not retreated far, and still mark the site of the faults; while there are other great plateau edges which are monoclinal flexures, and here the bent rocks yet appear. The great cliffs are everywhere adamantine structures of magnificence: they are terraced and buttressed, and cut with deep reëntering angles, and often set with towers, pinnacles, and minarets; they obstruct the traveler even more than mountain ranges; in fact, from the plain below, they appear as mountains built of naked rock. Where the rocks are limestones and hard sandstones, bold precipices are formed; but between these steep ledges the softer shales are often carved into a filigree of fantastic forms. A façade thus constructed of rocks of varying hardness in bands of many colors, in forms that resemble Titanic architecture, makes the scenery a constant wonder to the traveler. Where the edges of the plateaus are monoclinal folds, the inclined rocks are carved on another plan, giving variety to the scenery.

The streams usually have deep channels. Little rills born of showers and dying with the sunshine have often cut deep but narrow, winding gorges, at the bottom of which great caves are often found. The creeks have cut larger canyons, and the rivers have cut mighty canyons,—gorges sometimes hundreds of miles in length. So there are canyons along the rivers, smaller canyons along the creeks, still smaller canyons along the brooks, and picturesque canyons along the wet-weather rills; and the plateaus are thus divided by a labyrinth of deep gorges. While the diastrophism of the blocks has produced great plateaus, and while stream cutting and stream sapping have been dissecting them, vulcanism has been in progress; and old volcanoes are often found on the summits of the plateaus, and cinder cones are scattered in many places, and great sheets of lava have been poured out that have become the caps of table mountains, and other sheets have been piled one upon another so as to constitute imbricated mountains, and in a few places laccolitic mountains are found. Thus with cliffs, canyons, gorges, and volcanic mountains, the entire region is one of picturesque grandeur.

To the north there is a plateau known as the Uinta Mountains, having its greatest length in an east-and-west direction. It has a monoclinal flexure on each flank,—one at the north

and one at the south. Between these abrupt flexures the rocks are gently carved. Like many other of the plateaus, the southern edge was upheaved much more than the northern edge. This plateau was dry land during a part of Cretaceous time, and there were islands here during Eocene time. In Neocene time the entire plateau became dry land, and from that time on, the rate of upheaval was comparatively great, and through this range great lakes to the north were drained into lakes farther south. So the upheaval went on as the plateau was lifted; but the river was able to carve its way through the plateau, and still remained an outlet for the upper lakes during all Neocene time. In this period it was upheaved more than twenty thousand feet, yet the river cut its channel and preserved its course during all the time. The river came from the north, and impinged on this block about halfway in its course from east to west, then made its way into the heart of the block, next turned eastward for sixty miles, and finally turned again to the southwest, until it left the block at its southern margin. So the canyon was cut through a bluff that was slowly lifted by forces from below.

The small streams have all trenched deep gorges, between which minor plateaus are found; and sometimes the trenching has left behind great peaks, so that the plateau has received the name "Uinta Mountains." It is largely covered with forests, but the deep gorges often have cliffs of naked rock.

In the southeast there is a great plateau, on the western side of the Rio Grande del Norte, opposite the Santa Fe Plateau. The block is about eighty miles square. It was upheaved from the west side along a line which presents a general north-and-south direction. It was not faulted, but upheaved in monoclinal flexure, bringing up the Neocene rocks, Cretaceous rocks, Juratrias rocks, and Carboniferous rocks. The Carboniferous rested unconformably on granite, and the granite also was brought up to an altitude several thousand feet above the little valleys on the west. Looking at the edge of this plateau from the west, it appears to be a great range of mountains. The block itself was tilted eastward and to a slight extent southward. As it came up, the Eocene, Cretaceous, and Juratrias rocks were all washed away from the western margin of the plateau, leaving a summit of granite; but going eastward, rocks of all of these ages appear in order from the older to the younger. As the block was tilted, there was very little vulcanism on its western flank, but on the

east vast bodies of lava and ashes were poured out, so that on this eastern margin of the block great volcanoes were erected. The emission of matter from below was accomplished to an unusual extent by explosion, so that vast quantities of ashes were ejected, and these blew over the plateau, and thus beds of ashes scores and hundreds of feet in thickness were formed. As the volcanoes and ash beds were constructed, the main trend of the drainage was turned southward through Jemez River and its tributaries by a ramifying system of streams from the north, east, and west. These streams have often carved deep, narrow canyons, that reveal the structure of the vulcanic rocks above, and the sedimentary rocks below. Space forbids the further description of this beautiful plateau, with its granite range on the west, its volcanic peaks on the east and north, its beautiful valleys among the dead volcanoes; with deep gorges through which streams run, and hot springs that flow from the vulcanic rocks, and curious little faults that appear here and there, and strange forms that have been produced by corrasion, and lakes that have been filled and drained, and the forests with which the plateau is crowned.

To the south the San Francisco Plateau is found,—a table-land of great extent. It was upheaved as a block from south of west, and tilted to the east. All the Eocene and Cretaceous rocks have been washed away from its summit, and are found only on its flanks; but portions of the Juratrias remain. Through Eocene time it was deeply trenched by many streams. In Neocene time vulcanism prevailed, and a great system of volcanoes was built, and many cinder cones are found; often old channels were filled with lava, cinders, and ashes. The plateau is quite elevated, and the rainfall is nearly twenty inches annually; but the waters thus falling on the surface sink away into the lavas, cinders, and ashes, and are gathered below at a great depth in the old stream channels. Sometimes these underground waters excavate great caves below, and then the upper rocks fall in, so that many sinks are formed. In one of the cinder cones a crater lake is found, and scattered over the plateaus are many wonders. It is covered with a great forest, with intervening prairies that are gardens of wild flowers in midsummer.

Only three of the plateaus of the great number are described, but they serve as types for the entire region.

THE BASIN RANGES.

South of the Columbia Plateaus, and west and south of the Colorado Plateaus, is the great region of the Basin Ranges, extending far down into Mexico. It is a region of isolated diastrophic ranges, usually having a north-and-south direction, and often complicated with vulcanism. The blocks out of which the ranges are carved are uplifted abruptly, mainly by faults, but occasionally by steep monoclinal flexures, so that the rocks usually dip gently away to the other side. These simple diastrophic blocks are often greatly modified by vulcanism, and the lava from below is often piled up in peaks and small plateaus, while occasionally volcanic cones are found. The mountains are never high, and are often destitute of large trees, and sometimes are mountain deserts. Between these isolated ranges there are broad valleys with small branches extending into the mountains. The great valleys below are diastrophic basins which receive the sands and gravels washed down from the mountains, and are filled to the present surface from great depths below. In the mountains themselves narrow valleys have been trenched. Down these the streams flow until they are lost in the sands, so that their waters are not carried to the sea. Sometimes there are salt lakes in the valleys. Of these, Great Salt Lake and Pyramid Lake are the more important examples. In early Pleistocene time there were many more lakes of this character; and, as the climate was more humid, some of them, at least, found outlets to the sea.

The region is naturally divided by the Colorado River of the West. The district to the north is characterized mainly by closed basins, though near the Pacific Ocean there are many filled valleys which drain directly into the sea, and near the Colorado there are few. Southeast of the river all the basins have wet-weather drainage channels into the great river itself and the Gulf of California, or into the Rio Grande del Norte and Gulf of Mexico. The entire region is arid, usually having less than ten inches of rainfall annually over the filled basins. It is the desert region of the United States. The region east of the Colorado may ultimately be distinguished by another name: "Sierra Madre" would be appropriate. The mountains are more diverse, and the valleys more deeply trenched.

PACIFIC MOUNTAINS.

This is a great group of mountains and intervening valleys. The Cascade region is a diastrophic plateau on which vulcanic plateaus have been piled, and on them great volcanoes were elevated which are now extinct. The most picturesque peaks in the United States south of Alaska are here found, and in their gorges glaciers yet remain. From the crater of one of the volcanoes in Oregon there have been vast explosions, by which ashes and cinders were scattered widely over the adjacent country, and afterward the rocks about the crater fell into the depths below. The basin thus made has been deeply filled by snows and rains, and a lake has been formed of great extent and depth, known as Crater Lake. To the west of these mountains a river flows northward into the Columbia. The upper part of the valley is comparatively narrow; but along the lower two thirds there is a broad stretch known as the Sound Valley, which is formed by the upheaval of the Cascades on the east, and of the mountains near the coast on the west. At one time an arm of the sea extended up this valley in a great gulf, and since that time the land has been somewhat uplifted. It is thus a constructed valley between mountain ranges, and has been partly filled with sediment. To the west the Olympic Mountains stand on the north of the Columbia. The structure of these mountains is unknown. South of the Columbia, near the coast, are the Oregon Mountains, often called the Oregon Coast Ranges.

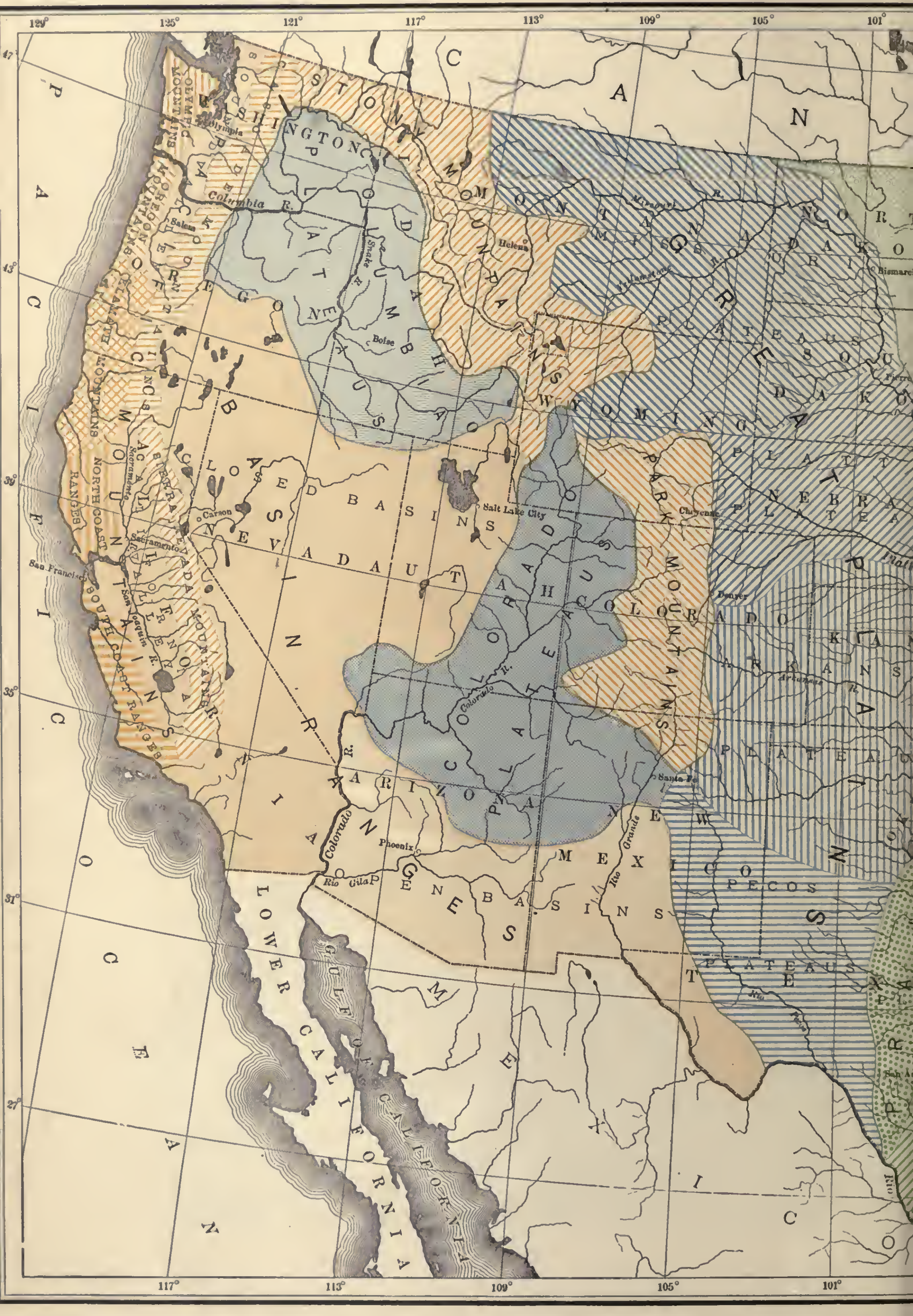
South of the Sound Valley and the Oregon Ranges there is a very irregular group of mountains, drained in part to the Columbia, in part to the Sacramento, but in chief part directly into the ocean. It is an upheaved archipelago known as the Klamath Mountains. South of the Cascade Range stand the Sierra Nevada. It is a great block upheaved from its eastern margin, and tilted westward. The displacement is by a complicated system of faults and folds, along which there has been much vulcanic action; and the coulees of lava have often obstructed the valleys, and formed lakes which have sometimes been filled by sediments until they were drained away. One of these streams, Truckee River, has its source far back in the block. In late Pleistocene time a series of coulees poured across it, and built a dam many hundreds of feet high, behind which Tahoe Lake has

been gathered, until now it runs over the dam, in which it has cut a small channel. Elsewhere in the Sierra there are other lakes having interesting histories. As the block tilted westward, the drainage is chiefly in that direction. The irregular streams have carved out many flaring, steep gorges, between which mountain ridges stand, diminishing in altitude to the valley of California. Along the western flank there has been much vulcanism; and the coulees have formed many plateaus which have been trenched by the streams.

To the west of the valley stand the North and South Coast ranges, which are mainly anticlinal folds, sometimes compressed and faulted, and very much broken into fragments. These coast ranges are severed where the San Joaquin joins the Sacramento and flows through the Golden Gate into the ocean. The bays about San Francisco are diastrophic basins modified by gradation. The valley of California is naturally divided into two parts, — the northern valley, drained by the Sacramento; the southern, by the San Joaquin. They are naturally treeless, gently rising to the mountains on either side. Not long ago geologically the sea occupied these valleys as a great gulf; but they have since been upheaved, drained, and covered with a deep accumulation of clay and sand washed from the mountains.

The scenery of the Pacific mountain region is greatly diversified, and has many contrasting features. The extinct volcanoes of the Cascade Range have towering peaks that are covered with snow during many months, whose glittering crowns, revealed through vistas of forest land or seen from the far-away ocean, ever inspire delight. With green forests below, gray slopes above the forests, and peaks of silver, their symmetry is wonderful. This aspect of the mountains entirely changes as the mountaineer ascends from valley to mountain height; then the wooded slopes are transformed into deep gorges covered with evergreen forests of giant trees; the gray zone above is transformed into crags, towers, and minarets of many but quiet colors; while above is the zone of silver, with its snows and glaciers. So the mountains are in uniform, — green, gray, and silver, — all resplendent in noonday sun. When the clouds come, the peaks are masked; but as they vanish or roll away, a changing panorama of splendor is presented.

The Sound Valley is mainly covered with forests of trees, tall and stately. Among the venerable giants younger generations



129°
125°
121°
117°
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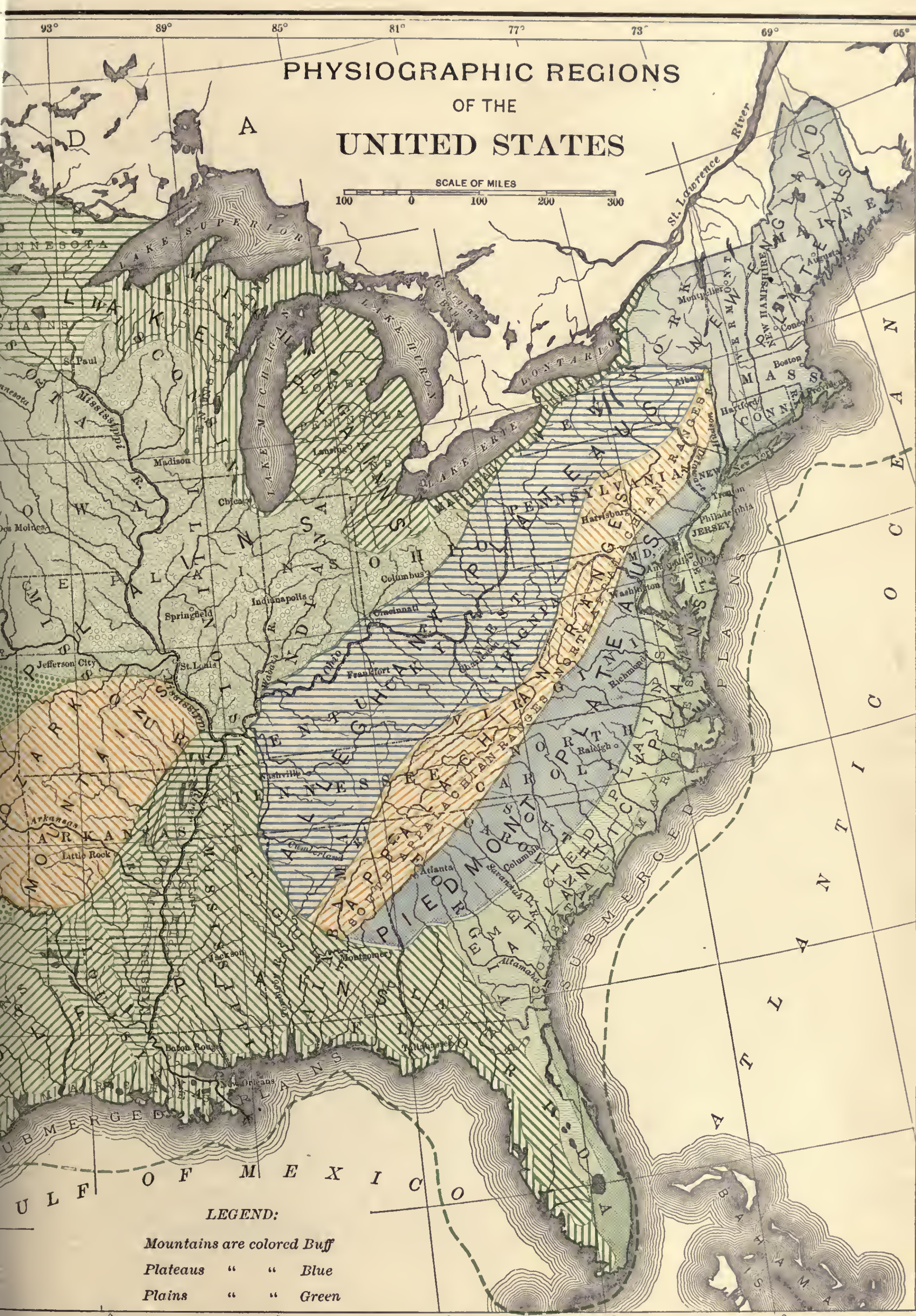
109°
105°
101°
PACIFIC OCEAN
OLYMPIC MOUNTAINS
Olympia
Columbia R.
Salem
Snake R.
Boise
Helena
Salt Lake City
Carson
Sacramento
San Francisco
San Joaquin R.
NORTH COAST RANGES
SOUTH COAST RANGES
KLAMATH MOUNTAINS
CLOSED BASINS
NEVADA
UTAH
ARIZONA
NEW MEXICO
WYOMING
PARK MOUNTAINS
Cheyenne
Denver
Santa Fe
Colorado R.
COLORADO PLATEAUS
Phoenix
Rio Gila
Rio Grande
Arkansas R.
PECOS PLATEAUS
LOWER CALIFORNIA
GULF OF CALIFORNIA
MEXICO
Bismarck


PHYSIOGRAPHIC REGIONS
OF THE
UNITED STATES
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LEGEND:
Mountains are colored Buff
Plateaus " " Blue
Plains " " Green
Bradley & Poates, Engr's, N

live; and pines, hemlocks, and cedars lift their bourgeoning heads to vie with their elders. On the ground dead and prostrate trunks lie, while others recline against the living. Among the dead and living trees there is an elaborate interlacing of vines, creeping, climbing, twisting, and weaving a woof of vine in a warp of branches. Over the mountains to the west these forests extend, losing but little of their luxuriance.

Descending from Mount Shasta into the valley of the Sacramento, the northern end of the great valley of California, cinder cones are seen in great numbers. On these cones the rains and snows fall and sink away, to reappear far away in great springs. Then the tributaries of the Sacramento roll down in deep gorges. On the eastern side, and on to the south for five hundred miles, stretches the great Sierra Nevada, with towering, irregular, and clumsy mountains on its eastern margin, cold, gray, and desolate. It is a region of gorges and peaks, but at their feet there are many beautiful lakes with clear emerald waters. Below the peaks is a region of forest. The traveler, in descending westward to the valley, passes from a zone where forests are low and gnarled by storms, until gradually the trees become more stately, and he reaches the groves of sequoias, — the great trees of the world, whose mighty forms record the history of many centuries of winters and summers. In the valley below, live-oaks are found with branches akimbo, and knotted fists ready for pugilistic fray.

Beyond the valley are the Coast Ranges, where the balm of the tropics bathes the winter with verdure, and boreal zones boon the summer with zephyrs.

THE ROCKY MOUNTAINS.—In an important sense all the mountains west of the Great Plateaus constitute a single group, though the regions into which they are divided are plainly demarcated. There is great diversity, and all known types are found; and there are large areas of plateaus and still larger areas of valleys; yet for some purposes it is convenient to use a general term for them all. For this purpose two names have been used,—"Rocky Mountains" and "Cordilleras." The term "Rocky Mountains" has sometimes been applied to the entire group of groups, both by writers and in popular speech. It has oftener been applied in a vague way to the Stony Mountains, the Park Mountains, the Columbia Plateaus, the Colorado Plateaus, and a part of the Basin Ranges, especially the southern district, or Sierra Madre. The term "Cordilleras" has been used by a few writers to cover the same region, but popular usage is confined mainly to the term "Rocky Mountains." This name has been used in this broader sense to cover the entire region by the officers of the general government, and has been woven into the federal laws with this meaning; so that official and popular usage coincide. For many years it has been used with this significance by the present writer.

PRESENT AND EXTINCT LAKES OF NEVADA.

By Israel C. Russell.

TOPOGRAPHY AND CLIMATE OF NEVADA.

The traveler who crosses the State of Nevada on the Central Pacific Railroad will observe that for much of the way the route follows the Humboldt River and crosses the "grain of the country." The mountain ranges trend northeast and southwest, and are separated by level-floored valleys. The valley of the Humboldt, however, is a striking exception to this rule. The river rises on the eastern border of the State, and flows westward for half its length before conforming with the direction of the mountain ranges. At many localities the traveler can see far off over the desert valleys to the right and left of his course, and cannot fail to be impressed with the fact that the depressions between the sharp, narrow ranges were formerly much deeper than now, and have been filled in or graded up, as it were, to approximately the same level.

Could the traveler scale one of the higher peaks that he passes, and obtain a wide-reaching view over the rugged land, the fact that the depressions between the mountain ranges have been partly filled would become more apparent. In general, the central parts of the valleys are level-floored; but at their borders the material with which they are filled slopes upward, and rests against the rocky sides of the inclosing mountains. The sculpturing of the mountains, and the abrupt manner in which their precipitous sides frequently plunge down to meet the alluvium in the valleys, indicate the depth to which their bases have become buried. Borings through the soft deposits

in the valleys show that their rocky bottoms are frequently at least two thousand feet below the present surface. Careful estimates based on the character of the mountain slopes, and on borings not only in Nevada but over a much larger region of which that State forms a typical part, indicate that in many instances the depressions between the mountains have been filled to a depth of at least four or five thousand feet.

Dirt and stones have been washed from the mountains into the adjacent valleys, and gradually reduced the inequalities of the surface, but still the topography remains exceedingly rugged. The sharp, angular mountains frequently rise from four to six thousand feet above the neighboring valleys. The coarser material, as well as much of the finer débris washed from the uplands, has been deposited about the mouths of the gorges through which it descended, and forms broad alluvial cones. The accumulations about the entrances of adjacent canyons are frequently confluent, and form a pediment for the angular peaks that seem to rest on them. The margins of each alluvial-filled basin slope down in gentle curves convex to the sky, and merge into the broad level area in the central part of the depression. When the openings between adjacent valleys are wide, the materials in their bottoms are united in such a manner as to form a single plain, through which the higher summits of the partially buried ranges project, and form island-like elevations known as *lost mountains.*

The topography is strikingly at variance with that of regions having an abundant and well-developed drainage. Many of the valley bottoms are uncut by stream channels, and are so inclosed by mountains that they would hold broad lakes before being filled to overflowing. Scores, if not hundreds, of such basins exist, but lakes are rare.

The traveler who visits Nevada will be impressed also with the arid and frequently decidedly desert character of the country. Forests are absent, except in a few limited areas on the higher mountains. One may ride for hundreds of miles through the valleys without finding a tree to shelter him from the intense heat of the summer sun. The prevailing vegetation is the sagebrush (*Artemisia*). This, with other desert shrubs, imparts a gray tint to the russet brown of the naked land. For months together not a drop of rain falls, and for weeks in succession the sky is without a cloud.

On the rain charts recently issued by the U. S. Weather Bureau, the rainfall of Nevada during the three months of spring, with the exception of a small area at the north, is below ten inches, and over a considerable portion of the west-central part is less than one inch. In summer it is less than one inch, and in fall and winter less than three inches, for the entire State. The precipitation for the year is represented as being less than ten inches, and over a large area in the west-central part is below five inches. The observations on which these generalizations are based were made from the early settlement of the country to the close of 1891, principally along the railroads, and do not show the depth of precipitation on the mountains. They fail to some degree, also, in expressing the extreme aridity of some of the valleys in the western and central parts of the State, for the reason that at times, as I have been informed by settlers, there is no rain at all in those regions during eighteen or more consecutive months.

In contrast with the exceedingly arid character of Nevada, I may recall, for the sake of illustrating by contrast, the fact that in the Mississippi Valley the mean annual precipitation is from 30 to 40 inches, increasing southward to 50 or 60 inches. In portions of Florida and on the coast of North Carolina it exceeds 60 inches, and on the coast of the State of Washington is more than 100 inches.

One other series of facts in the physiography of Nevada should be borne in mind by the student who wishes to know the life history of her lakes.

The small rainfall and clear skies are accompanied by a high mean annual temperature. The humidity of the atmosphere is low, and evaporation excessive. The annual loss by evaporation from a surface of standing water exposed to the sun and winds ranges from 70 to more than 100 inches. On a given area in the valleys the amount of water that could be evaporated annually is from 20 to 80, and in exceptional years 100, times the mean annual precipitation.

The marked diversity in the relief of the land, and the character of the climate, determine the principal episodes in the histories of the lakes to which attention is here invited.

Many of the valleys are broad and deep. Under more favorable climatic conditions, they would be transformed into extensive lakes, but at present are without standing water throughout

the year. The deep porous soil acts like a sponge, and is capable of retaining much more water than the clouds now furnish.

There is a second source, however, from which the desert valleys derive water, that must not be ignored.

The long parallel mountain ranges are, as a rule, steep on one side, and slope much more gently in the opposite direction. Each of these sharp, narrow ranges is the upturned edge of a block of the earth crust, separated from the adjacent block by profound fractures. The fracture which permitted this unequal tilting commonly follows the base of the steeper side of a range, while the depressed border of the fracture underlies a partly filled valley. This "basin range structure" is shown in the ac-

Ideal Section through Pyramid and Winnemucca Lakes, Nevada.

companying generalized section. The breaks referred to frequently admit of the escape of water from sources deep below the surface, and copious springs result. In many instances the water flowing from these fissures is highly heated, showing that it rises from such a depth that its temperature is raised on account of the general interior heat of the earth, or else that the walls of the fissure have undergone recent movement, and by their friction elevated the temperature. These fissure springs are fed by the rain falling on distant regions, no one knows where, and furnish an important adjunct to the meager rainfall in the region where they rise. Much of Nevada would be impassable in summer were it not for the waters that reach the desert valley through fractures in their bottoms. The spring waters bring with them large quantities of mineral matter in solution, which is added to the lakes to which they may become tributary, or, when evaporated from the adjacent surfaces, appears as a white, saline incrustation.

THE PRESENT LAKES.

The nature of the topography of Nevada, and the character of the climate, lead to the formation of two classes of water bodies. These may for convenience be designated as *ephemeral lakes* and *perennial lakes*. The former are especially character-

istic of the vast arid region of which Nevada is a typical part, and merit their name because of their brief existence; the latter hold their autonomy for many consecutive years, and even for centuries, and are fresh or saline according as they overflow or are completely landlocked.

Ephemeral Lakes.—Could one be so situated as to obtain a bird's-eye view of Nevada, and watch the coming and going of the seasons, the manner in which many lakes are born in the desert valleys, live their brief lives, and pass away, would appear like the changing views in a panorama.

When the clouds gather in dark, gloomy masses about the mountain tops, and gradually expand until they bridge over the intervening basins, the rain falling from them descends most abundantly on the uplands, and in less quantity on the parched valleys. Streams fed by the falling raindrops course down the mountains, washing away the loose material that frequently clogs their channels, and reach the valleys heavily loaded with silt, and not infrequently roll along bowlders many tons in weight. These roaring torrents sometimes disappear beneath the surface on reaching the border of a valley, and add their loads to the deposits left by previous floods. The water that thus disappears emerges again when the subsoil becomes saturated, and gathers in the lowest depressions. The streams that are not wholly absorbed by the porous alluvium flow on with diminished volume in bifurcating channels, and, together with the rain that falls in the valley, finally spread out and form shallow lakes. Should the storm continue, the sheets of water in the valleys will expand, and possibly become many square miles in area. Such lakes are always shallow, and always yellow with mud in suspension. When the sun breaks through the storm clouds, evaporation becomes active, and the lakes gradually contract their boundaries, and perhaps in a few hours or in a few days are entirely dissipated. When the water has disappeared, absolutely barren mud plains remain, which harden under the sun's heat, and become cracked in all directions as their surface contracts in drying. The lake beds then have a striking resemblance to tessellated pavements of cream-colored marble, and soon become so hard that they ring beneath the hoof beats of a galloping horse, but retain scarcely a trace of his footprints.

Such bare, level mud plains are characteristic features of the

greater part of the valleys of Nevada, and are known in Mexico and adjacent portions of the United States as *playas*. The lakes to which they owe their origin are termed *playa lakes*.

These ephemeral water bodies frequently come and go almost as erratically as the shadows of the clouds cast on their own tawny surfaces. In other instances lakes of the same type appear during the winter months, and remain until the heat of summer reaches a maximum; they then give place to smooth plains of mud of the same character as those left by the more transient water sheets. Still other playa lakes are for a time perennial, and only evaporate to dryness during seasons of unusual aridity. The playa lakes with long periods of oscillation approach the condition of the lakes which have never been known to become dry. Ephemeral and perennial water bodies are thus united in one series. There is no rigid boundary between them; but it is convenient to select well-marked types to stand as representations of the two extremes, just as the naturalist does when he divides animals into genera.

Lakes of the Black Rock and Smoke Creek Deserts.—The largest ephemeral lake of Nevada is formed during winter months on what is known as Black Rock Desert in the northwestern part of the State (see Plate I.). This desert valley is irregular in shape, and has lateral valleys opening from it. Its length from northeast to southwest is over one hundred miles, and its average breadth twelve or fifteen miles. In summer it is almost entirely without tributary streams, except such as are fed by hot springs. In winter many brooks descend the mountains to the east and west; and the channel of Quinn River, which enters the basin from the northeast, is transformed into a veritable river. The course of this stream in summer is marked only by a dry channel, with an occasional water hole; but in winter it is flooded so as frequently to be impassable to a man on horseback, and has a length of upward of a hundred miles. Its waters then spread out on Black Rock Desert, and at times form a long narrow lake from 450 to 500 square miles in area. Although seldom over a few inches deep, it is impassable on account of the softness of the mud forming its bottom. Many times the "lake" is a vast sheet of liquid mud, and for this reason is known as "Mud Lake" by the settlers of the region. This name is not distinctive, however, as many other playas have the same name attached to them.

Black Rock Desert is not closed at its southern end, but opens out into another deep basin, known as Smoke Creek Desert. At the place of union, rocky headlands project from the mountains on the east and west, and approach within about five miles of one another. Where this constriction occurs, there is a slight rise in the valley bottom, but sufficient to divide the water that enters the basin and leads to the formation of two lakes. The lake formed during the winter on Smoke Creek Desert is not as large as its companion to the north, but is sometimes 25 to 30 miles long and 5 miles wide. In all of its essential features it is a counterpart of the one just described.

The winter lakes on Black Rock and Smoke Creek deserts, as in many other similar instances, do not occupy the entire valley bottom, but are surrounded by a broad fringe of what to the eye appears level land. This broadening tract is covered with sagebrush and other desert shrubs. In early spring many flowers beautify the ground, and fill the air with a faint perfume. The playas left by the desiccation of the lakes, however, are always barren. Not a plant takes root in their baked and hardened surfaces. Where these mud plains meet the surrounding areas clothed with desert shrubs, there is often a belt of ground that is soft and marshy in winter, and frequently retains something of this character after the lakes have disappeared. In summer it becomes white with salts brought from below by ascending water, and left on the surface when evaporation takes place. These efflorescent deposits become unusually abundant about some of the hot springs, and are then apt to contain borax in addition to the sulphate and carbonate of soda, common salt, etc., which make up the bulk of such incrustations.

Lakes of Carson Desert.—The Carson Desert in west-central Nevada, shown on the map forming Plate I., is a basin surrounded by irregular mountains. Its length from northeast to southwest is about 75 and its width 25 miles. It receives the waters of Carson and Humboldt rivers, but has no channel of escape. Both of these streams are worthy to rank among rivers, if their length and volume in the winter season are alone considered.

Carson River rises on the eastern slope of the Sierra Nevada, and has a length of 125 miles and a drainage area of about 1,000 square miles. Humboldt River is fully 300 miles long, and drains a region of small rainfall, in which the divides are frequently

indistinguishable. The area of its hydrographic basin may be variously estimated, but is in the neighborhood of 7,000 or 8,000 square miles. This is the largest stream that has its source in the central area of the arid region of which Nevada forms a typical part, and is abnormal in several particulars. Each of these streams is exceedingly variable in volume. In winter they carry several hundred, in the case of the Carson River fifteen hundred, times as much water as during the average summer stage.

The waters of the Carson and Humboldt spread out on the Carson Desert, and are there evaporated. When flooded, they form two sheets of water, known as North Carson and South Carson lakes. These lakes are frequently designated as "The Sink of the Humboldt" or "Humboldt Sink," and "The Sink of the Carson;" the popular belief being that the waters escape by subterranean outlets, or *sink* below the surface. This is not the case, however, as it can be proven that the inflow is counterbalanced solely by evaporation. North Carson and South Carson lakes are of the playa type, but are more persistent than the lakes of Black Rock and Smoke Creek deserts. They sometimes hold their integrity for a succession of years, but evaporate to dryness during seasons of more than usual aridity. North Carson Lake is rudely elliptical in outline, and is from 20 to 25 miles across from east to west, and about 14 miles broad from north to south. That its depth is never over a few feet, has been shown by examining its bed when dry.

South Carson Lake, when at its maximum as known in recent years, is from 4 to 5 miles in diameter, and about 4 feet deep. Its depth is unusual for a playa lake; and for this reason, and because its feeding stream rises in high mountains, it is more constant than many other examples of its class.

Variations in the extent of the lakes of the Carson Desert have been more marked in recent years than formerly, for the reason that the streams supplying them are being used for irrigation. They are now more apt to become dry, and pass to the condition of playas during the summer, than when first known to the settlers of the region. They still serve, however, to show the connection that exists between the ephemeral lakes born of a single shower, and evaporated to dryness after a day or two of sunshine, and perennial water bodies that endure for a term of years.

Lakes of other Inclosed Basins.—Diamond valley, to the north of Eureka, furnishes another example of the manner in which a delicate balance between precipitation and evaporation leads to striking changes in the aspect of an inclosed basin. In summer this valley is exceedingly desolate, and a part of its area is white with salt. In winter the streams from the surrounding mountains are revived, evaporation decreases, and a lake is formed in the lower part of the depression. The previously precipitated salts which give the desert something of a wintry aspect during months of excessive dryness, are dissolved, and a lake similar in appearance to the normal lakes of humid regions appears in its place. Year after year this fluctuation goes on, and the appearance of the valley changes in sympathy with the unseen forces that control temperature and humidity.

In the central part of the area of interior drainage between the Sierra Nevada and Wasatch Mountains, there rises a conspicuous range known as the East Humboldt Mountains. These are snow-capped in winter, and repeat on a smaller scale many of the conditions resulting from the great elevation of the mountains bordering Nevada on the west.

To the east of the East Humboldt Mountains there are three lakes, known in their order from south to north as Ruby, Franklin, and Eagle lakes. These hold the same relation to the lofty peaks adjacent to them on the west as Pyramid and other lakes to be described occupy with respect to the Sierra Nevada. The lives of the lakes supplied by the drainage of the East Humboldt Range are less secure, however, than in the case of the larger lakes fed by streams from the greater range to the west. In winter they are flooded, the water supply being in part furnished by fissure springs; and in summer they decrease in area, and occasionally their basins become dry.

Ruby Lake, when in its normal winter condition, is about 16 miles long, and has a nearly uniform width of perhaps 2 miles. It is separated from Franklin Lake, to the north, by a narrow gravel bar formed by waves and currents in an extinct water body much larger than both of the present lakes combined. Franklin Lake is 15 miles long, with an average width from east to west of 4 miles. Eagle Lake, 22 miles northward from the one just mentioned, is more irregular than its companions, and is about 7 miles in diameter.

The waters of these lakes are slightly alkaline, but in winter and spring are not unpleasant to the taste. They are playa lakes with a longer period than most of their companions of the same type, and might with propriety be termed *semiperennial.* To this provisional subclass might also be referred the lakes of the Carson Desert, since, previous to the time their tributary streams began to be diverted for irrigation, they were evaporated to dryness only in occasional years of great aridity.

Hundreds of other inclosed basins, particularly in southern Nevada, are partially flooded in winter in a similar manner to those already enumerated, and become desert plains of hardened mud in summer. Various portions of the region surrounding Nevada, and especially those embraced within the boundaries of Utah, Arizona, and California, experience changes similar to those just described, and illustrate some of the most striking peculiarities of a region where the topographic and climatic conditions favor the existence of temporary lakes.

PERENNIAL LAKES.—Lakes which exist for a term of years, and hence termed *perennial*, may be conveniently divided into two classes: namely, those that overflow, or *normal lakes;* and those that do not rise sufficiently to find an outlet, or *inclosed lakes.* By *normal lakes* is meant the class of lakes characteristic of humid regions, and hence the most abundant and most familiar the world over. They are commonly expansions of rivers, and overflow.

These two subclasses, as in the case of ephemeral and perennial lakes, are not limited by definite boundaries. Inclosed lakes are sensitive to climatic changes, and may increase in volume until their surfaces are raised to the level of the lowest point in the rims of their basins, and be transferred temporarily or permanently, if the climatic conditions remain favorable, to the list of those which usually give origin to streams. Numerous examples in Nevada and adjacent regions might be cited of lakes which have been known to undergo changes that have transferred them many times from one subclass to another.

Some of the ephemeral lakes of Nevada which are not sufficiently permanent to have a name, or to be recognized as lakes by the settlers of the region where they occur, overflow during their brief existence, and, if this one feature is alone used in classification, would belong to the class of water bodies characteristic of humid regions. It will be seen, therefore, that the

classification proposed above is simply for convenience, and does not imply stable conditions.

Normal Lakes.—The list of normal lakes in Nevada is short. There are two only—Lake Tahoe and Lake Humboldt—that can consistently be placed in the same category as the tens of thousands of lakes found in humid regions.

Lake Tahoe.—This "Gem of the Sierras," as it has been aptly called, is situated partly in Nevada and partly in California. The depression it occupies, like the majority of the basins described in this paper, was formed by unequal movement of large masses of the earth's crust (*diastrophism*). The outline of the valley in the mountains which the lake has appropriated has been modified to some extent by streams and glaciers, but not sufficiently to destroy the characteristic features resulting from the great disturbances that gave it birth.

Lake Tahoe is surrounded by some of the finest scenery of the Sierra Nevada, and is especially pleasing on account of the breadth of view obtained from many points on its shores. The mountains surrounding it are clothed with coniferous forests to within a few hundred feet of their angular summits. Their more rugged lines are thus subdued, and given a picturesqueness that is entirely lacking on the shores of the desert lakes.

This lake is 21 miles in diameter from north to south, and 12 from east to west. It is 195 square miles in area, and receives the drainage of 922 square miles of territory. Its elevation above the sea is 6,202 feet. Soundings made by Professor John Le Conte gave a depth in the central part of 1,645 feet. This measure may be exceeded when a more systematic survey of the contour of the bottom is made. Next to Crater Lake, Oregon, it is the deepest lake yet measured in North America. Its waters, of great purity and of wonderful transparency, are inhabited by splendid trout and other fishes in abundance. The overflow escapes through a rocky gorge, and forms Truckee River,—a clear, swift stream, which, after a tortuous course of about 100 miles, empties itself into Pyramid and Winnemucca lakes.

Lake Tahoe, situated among mountains that rise from seven to ten thousand feet above the sea, the swift bright river flowing from it, and the alkaline and saline lakes formed by the retention of its surplus waters in desert valleys, furnish a geographical unit in which many of the marked contrasts between humid and arid lands are well illustrated. A careful study of this

single, circumscribed drainage area would furnish one of the most complete and instructive lessons in physical geography that our country affords.

Mountain Tarns.—To make an account of the existing lakes of Nevada complete, it is necessary to mention a few small tarns situated in deep recesses on some of the higher mountains. In the portion of the Sierra Nevada included within the boundaries of the State, on the East Humboldt Range, and about Jeff Davis Peak, there are small basins at elevations of from eight to ten thousand feet above the sea, which are filled usually to overflowing with clear, sweet water. These depressions are either in solid rock, or are formed in part by terminal moraines left by ancient glaciers. They are of a type common in mountains that have been ice-covered, but are exceptional, and are not a characteristic feature of the arid region in which we are now especially interested.

Humboldt Lake.—Humboldt River, after flowing for some three hundred miles through treeless valleys, and just before reaching the Carson Desert, meets an obstruction that holds its waters in check, and causes an expansion known as Humboldt Lake. The dam which blocks the way is an immense gravel bar which extends completely across the valley, and was formed in an extinct lake (Lake Lahontan, to be described later). This bar, as may be seen from the map forming Plate IV., has many of the features of a railroad embankment. It is formed mostly of gravel and sand swept from the margins of the old lake and deposited in deeper water when the loaded currents were deflected from the shore. Its length from the cliffs on either side of the valley is about 4 miles. Its top is from 50 to 125 feet above the adjacent plain. The river was held in check by this obstruction when the old lake was lowered below its crest and formed a secondary lake. At some time in its history the lake overflowed, and cut a narrow channel through the obstruction that held it, and was partially drained. In recent years an artificial dam has been placed in the opening, which, when in repair, causes the lake above to expand. During summer seasons Humboldt Lake seldom overflows, and is then the lower limit of the drainage system of the river from which it takes its name; but in winter and spring the waters escape southward, and spread out on the desert so as to form a shallow water sheet, known as Mirage Lake. Farther southward, on the northern part of Carson Desert, the water

again expands, and forms the principal source of North Carson Lake, already described.

In the summer of 1882, when examined by the writer, Humboldt Lake covered an area of about 20 square miles, and did not overflow. Its waters were somewhat alkaline, owing to evaporation from its surface and from the river feeding it. Its depth was about 12 feet over the greater part of its area.

The abnormal character of the lakes of Nevada, as would appear to a visitor from lands enjoying a more humid climate, is shown by the fact, that, with the exception of mountain tarns, there are only two lakes belonging to the class normal to regions of abundant rainfall. Of these, one is but partly in Nevada and at a high elevation among mountains, and the other overflows only during the rainy season, and, if its natural discharge had not been obstructed, might possibly be included among ephemeral lakes.

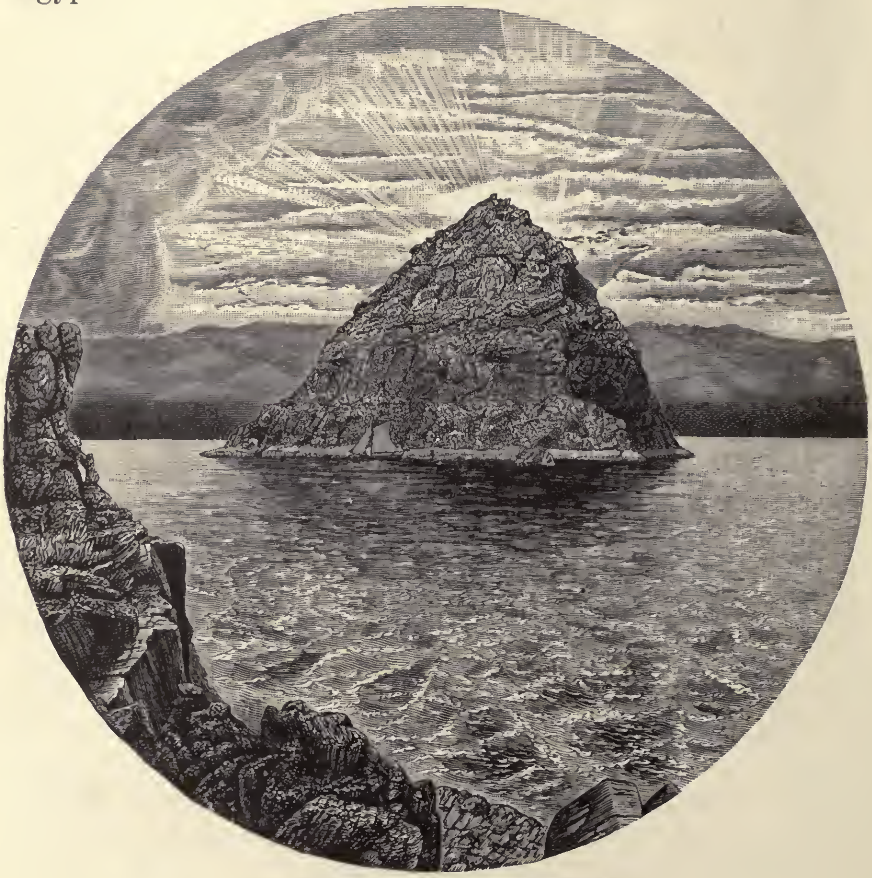
Inclosed Lakes.—The lakes of Nevada which, next to the playa lakes, best illustrate the climatic conditions there prevailing, are the perennial lakes that do not overflow. Here again the list is short. The only examples that can be found are Pyramid, Winnemucca, and Walker lakes. The characteristics of these lakes are of interest not only in the study of the present geography, but because they form a supplementary chapter to the history of Lake Lahontan, which occupied the same region at a comparatively recent date.

Pyramid and Winnemucca Lakes.—The Truckee River, as already stated, discharges into both Pyramid and Winnemucca lakes. On reaching the valley in which these lakes are situated, the river divides in much the same manner as many streams send off distributaries on flowing over their delta. The proportion of water reaching either lake is variable, and depends on the nature of the obstruction formed in the channels of the river below where it divides. At times the entire supply goes to a single lake, and occasionally one lake becomes tributary to the other. The lakes are subjected to fluctuations from this cause, as well as from variations in climatic conditions.

The accompanying map of Pyramid and Winnemucca lakes (Plate II.), made in 1882, will obviate the necessity of a description of their more pronounced features.

Pyramid Lake was first made known to civilized man by General Fremont, who traversed its eastern shore in 1844, and named

it in reference to the peculiar form of an island near its southern end. This island, as may be seen from the accompanying illustration, has a remarkable resemblance to one of the Pyramids of Egypt.



Pyramid Island, Pyramid Lake, Nevada.

The lake has a length of 30 miles, and near its northern end is 12 miles broad. Its area in September, 1882, was 828 square miles. Winnemucca Lake at the same date was 29 miles long, with an average breadth of $3\frac{1}{2}$ miles, and an approximate area of 91 square miles.

The sub-lacustral contours given on the map (Plate II.) indicate, that, if the waters of these lakes were withdrawn, the basins they occupy would have approximately the same characteristics as may be observed in many adjacent valleys in which playas occupy the lowest depressions. This fact, together with

others that will be mentioned later, suggests that even these broad lakes were formerly reduced to the condition at present illustrated by many ephemeral lakes.

The waters of both Pyramid and Winnemucca lakes are saline and alkaline. The chemical composition of the matter in solution is shown in the table on p. 117. Like all inclosed lakes, they are sensitive to climatic changes, and exhibit both seasonal and secular variations. They record the net balance between rainfall and evaporation, and rise and fall with changes of humidity much as a barometer fluctuates with variations in atmospheric pressure. This fact is the more apparent, since the lakes receive scarcely any water supply from other sources than the Truckee River. The springs tributary to them are few in number and small in volume. The rain falling on the adjacent land can be safely assumed as not exceeding five inches annually, and is so distributed that it is mostly absorbed by the parched soil, or evaporated, before it can gather in rills and find its way to the lakes.

Much might be said of the rugged picturesqueness of the mountains about these dead seas, of the peculiar islands breaking their surfaces, of their abundant fish life, of the varying tints of their waters, and of the manner in which carbonate of lime is being eliminated from them through the agency of low forms of plant life; but space will not permit.

Walker Lake.—This lake, like the two just described, is fed almost entirely by the snow and rain falling on the Sierra Nevada. The immediate source of supply is Walker River. Surveys made in 1882, from which the map forming Plate III. was constructed, showed that Walker Lake was then $25\frac{3}{5}$ miles long from north to south, and had an average breadth of between $4\frac{1}{2}$ and 5 miles. Its area was about 95 square miles. The greatest depth obtained by such soundings as it was practicable to make was 225 feet. The waters are alkaline and unfit for human use, although drunk by animals. The chemical composition is given on p. 117.

The west shore of Walker Lake is bordered by a precipitous mountain range, which rises from the water's edge so abruptly that not room enough for even a bridle path intervenes. This mountain ridge is the upturned border of a tilted block of the earth's crust, and is bounded on the east by a profound fracture. The block on the east side of the fracture has subsided with

reference to the west side, and the depression thus formed is occupied by the present lake. Like many of the valleys of Nevada, this is a typical fault basin. The exceptional depth of the lake is probably due to recent movements of the fault that gave it origin.

Crater Lakes.—On the western side of Carson Desert there are two circular depressions with elevated rims that are filled with intensely alkaline water. These are known as Soda Lakes, and, from their proximity to a former settlement called Ragtown, are sometimes designated as the "Ragtown Ponds." The larger lake has an area of 298½ acres; and the smaller is a pond of variable size, much modified in recent years by excavations. The rim of the larger lake in its highest part rises 80 feet above the surrounding desert, and is 165 feet above the lake it incloses. The outer slope of the rim is gentle, and merges imperceptibly into the surface of the surrounding desert; but its inner slope is abrupt and in places precipitous. A series of careful soundings made in the lake show its maximum depth to be 147 feet. The total depth of the depression is therefore 212 feet.

This great hole in a nearly level plain, as shown by the structure of its walls and the nature of the material composing them, is of volcanic origin. It is a volcanic crater from which dust, lapilli, and bombs a foot or two in diameter, have been violently ejected, but which did not pour out liquid lava. The diameter of the crater from opposite points in its rim varies from a mile and a half to two miles. This volcano is situated in the basin formerly flooded by Lake Lahontan, and was in activity before that lake disappeared, as well as at a later date. The waters now occupying the crater find their way to it by percolating through the thick lake beds that floor the Carson Desert, and owe their high percentage of saline matter to the salts dissolved from the rocks through which they find their way.

The Soda Lakes are the basis of a considerable industry in carbonate and bicarbonate of soda. The various salts they contain are indicated in the table on p. 117. These lakes are exceptional in character, and have but slight bearing on the study of climatic change from which most of the lakes of Nevada derive their chief interest.

Analyses of Lake Waters.—In order to complete an outline of the data now available concerning the existing lakes of Nevada, the following table, showing the chemical composition of the matter in solution in their waters, is here inserted. Analy-

ses of two saline and alkaline lakes in the regions adjacent to Nevada are also presented for comparison.

Analyses of the Waters of Lakes in the Arid Region[1] *(Parts in 1,000).*

Constituents.	Abert Lake, Oregon.[2]	Great Salt Lake, Utah. (1869.)	Humboldt Lake, Nevada.	Soda Lake, Nevada.	Pyramid Lake, Nevada.	Walker Lake, Nevada.	Winnemucca Lake, Nevada.	Lake Tahoe, California-Nevada.
Sodium (Na)	14.245	49.690	.27842	40.919	1.1796	.85535	1.2970	.0073
Potassium (K)	.521	2.407	.06083	2.357	.0733	Trace.	.0686	.0033
Calcium (Ca)	–	.255	.01257	–	.0089	.02215	.0196	.0093
Magnesium (Mg)	–	3.780	.01648	.245	.0797	.03830	.0173	.0030
Chlorine (Cl)	13.055	83.946	.29545	40.851	1.4300	.58375	1.6934	.0023
Carbonic acid (CO_3) . .	9.199	–	.20126	16.858	.4990	.47445	.3458	.0287
Sulphuric acid (SO_4) . .	.685	9.858	.03040	11.857	.1822	.52000	.1333	.0054
Phosphoric acid (HPO_4) .	–	–	.00069	–	–	–	–	–
Boracic acid (B_4O_7) . .	–	Trace.	Trace.	.286	–	–	–	–
Silica (SiO_2)	.224	–	.03250	.278	.0334	.00750	.0275	.0137
Hydrogen (in bicarbonates)	.056	–	–	–	–	–	–	–
	37.985	149.936	.92860	113.651	3.4861	2.50150	3.6025	.0730

1 Compiled principally from Table C, in U. S. Geological Survey Monograph, vol. xi.

2 Analyses by T. M. Chatard, American Journal of Science, ser. 3, vol. xxxvii., 1888, pp. 146–150.

The analysis of the water of Lake Tahoe shows that it is of greater purity than the average of fresh-water lakes and streams.

Summary respecting the Existing Lakes.—As may be seen from a glance at a map of Nevada, all the larger lakes that diversify her surface are near the western border, and are supplied by precipitation on the Sierra Nevada. Hundreds of basins, some of them scores and even hundreds of square miles in area, and so inclosed as to be suitable for holding broad lakes, exist throughout the State, but the aridity of the region precludes their being occupied by perennial water bodies. In many instances the annual rainfall in these desert basins is so meager that it is at once absorbed by the thirsty soil, or returned to the atmosphere as vapor, and not even ephemeral lakes are formed. This is especially true of the southern portion of the State, where no lakes occur except a few pools fed principally by fissure springs.

Should the Great Basin, as the area of interior drainage between the Sierra Nevada and Wasatch Mountains is termed, experience a change of climate of such a nature that the rainfall would be increased or evaporation diminished, the most obvious result would be the appearance of lakes in valleys that are now either dry throughout the year or hold playa lakes, and the expansion of the perennial lakes. The lakes

now supplied by streams from the Sierra Nevada, and the much smaller lakes at the base of the East Humboldt Mountains, would expand, and invade the adjacent valleys until they exposed sufficient surface to the atmosphere to counterbalance the inflow by evaporation. If before this stage was reached a lake rose sufficiently to find an outlet, it would overflow, and become tributary to some lower basin. The manner in which the present perennial lakes fluctuate, and the appearance and vanishing of playa lakes from season to season or in response to climatic oscillations having a longer term, suggest that only moderate climatic changes of the nature above indicated would be required to produce marked results in the appearance of the basins of Nevada.

The study of the surface geology of the Great Basin has shown that a climatic change of the nature just suggested did occur at a time not remote. The streams from the mountains increased in volume; many channels were occupied by flowing water that are now dry throughout the year; lakes appeared in many and probably in all of the inclosed basins that are now arid; the perennial water bodies expanded until they became veritable inland seas. The records of the time when Nevada was a lake region are fresh and easily read. Let us see what thoughts their study will suggest.

EXTINCT LAKES.

Intimately associated with the lakes in the valleys of Nevada, referred to above, are the records of glaciers on the Sierra Nevada, East Humboldt, and other mountains. For this and other reasons the extinct lakes here considered are referred to the Pleistocene division of the earth's history, or the time immediately preceding and merging into the time of man.

PLEISTOCENE LAKES.—Many valleys of Nevada might be enumerated which were occupied by lakes previous to the present time of aridity. There is probably not an inclosed basin in the State but what had its lake during Pleistocene times. What is now in great part a desert land was then a lake region with as great a water surface, in reference to its area, as the present lake region of central New York or of northern England. Unlike many lake regions at the present day, however, a large number of these ancient water bodies did not overflow, and at times at

least were saline and alkaline. The configuration of the land was such as to lead to the existence of two great inland seas that outranked their neighbors, the histories of which are of unusual interest.

One of these seas, named Lake Bonneville, occupied Salt Lake valley, Utah, and several depressions opening from it, and was supplied mainly by streams flowing westward from the Wasatch Mountains. A contemporary lake, called Lake Lahontan, situated in northwestern Nevada, and extending into California, was supplied principally by streams flowing eastward from the Sierra Nevada. Lake Bonneville was the larger and deeper, and overflowed. Lake Lahontan, on the other hand, never overflowed. Owing to the absence of an outlet, it underwent many fluctuations in volume and composition, and left the most interesting and instructive chemical records of any lake known. Lake Lahontan was 886 feet deep in the deepest part, had an area of 8,422 square miles, and received the rainfall of 40,000 square miles.

The regions draining to these two great lakes occupied the entire space between the Wasatch Mountains and the Sierra Nevada, and for a distance of 25 miles near the northern part of the Utah-Nevada boundary their hydrographic basins had a divide in common. The smaller Pleistocene lakes at the base of the East Humboldt Mountains, previously mentioned, were situated to the south of these two drainage areas.

LAKE LAHONTAN.—Should a climatic change occur of such a nature that it would allow Pyramid, Winnemucca, and Walker lakes to expand until they became confluent and invaded many adjacent valleys, and continued to increase in depth until the sounding line in the deepest part showed 886 feet of water, the appearance of Lake Lahontan at its highest stage would be practically restored.

The outline of the lake is indicated on Plate I., from which the valleys it occupied, and the extreme irregularity of its outline, may be ascertained at a glance. One of the peculiar geographic features is that the lake surrounded a large, irregular island, on which there was a smaller lake. So far as known, this island lake did not overflow. A broad playa now marks its site.

The records left by Lake Lahontan during its various fluctuations may be grouped in two main classes, physical and chemical.

THE PHYSICAL RECORDS.—The rim of the Lahontan basin has been traced throughout its entire extent, and found to be unbroken by a channel of overflow. The water body it held was therefore an inclosed lake, and, like others of its class, must have been subject to repeated fluctuations of level. That such was its history, is also evident from the multitude of terraces still remaining as records of its changes. In this as in all abandoned lake basins, the elements of shore topography to which we turn for a large part of the history of the vanished waters are terraces, sea cliffs, embankments, and deltas.

Terraces and Sea Cliffs.—The most common of the records inscribed on the borders of the Lahontan basin are wave-cut terraces. These may be traced through a large portion of the basin, but are most distinct on the borders of the larger deserts.

In traveling over the Central Pacific Railroad between Golconda and Wadsworth, one is seldom out of sight of the long horizontal lines drawn by the waves of the ancient lake on the shores that confined them. Records of the same character may be traced continuously about the borders of the Black Rock and Smoke Creek deserts, and are strongly defined along the bases of the mountains overlooking Pyramid and Winnemucca lakes. They are again plainly legible on the steep slopes bordering Walker Lake, as may be observed by the traveler over the Carson and Colorado Railroad.

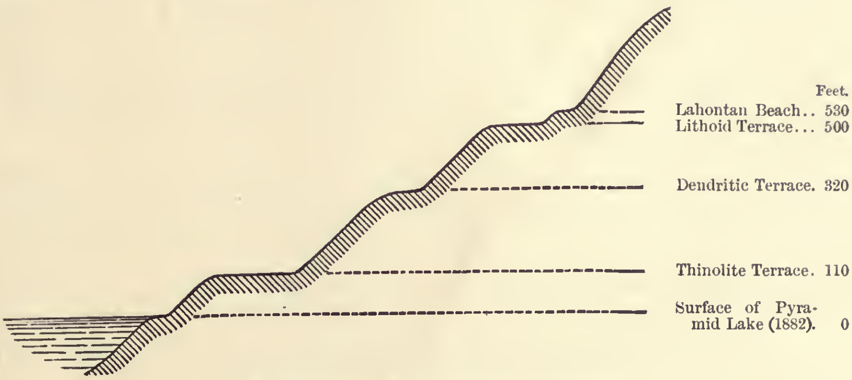
The highest of these numerous shore lines has been named the Lahontan Beach, as it records the highest water stage of the former lake. Its elevation above the sea is 4,343 fee at Mill City, and from 4,418 to 4,427 feet at the lower end of Humboldt Lake. These measurements, together with many others, show that the old beach is not now horizontal. Movements have taken place principally along numerous fault lines, and the relief is not now precisely the same as when the old lake existed. An average of the various measurements indicates that the present elevation of the Lahontan Beach is about 4,378 feet above the sea. This is the nearest approximation we can make to its original altitude.

Besides the Lahontan Beach, there are three other water lines of sufficient importance in the history of the lake to deserve special designation. One of these is a strongly defined terrace 30 feet below the Lahontan Beach, and at the upper limit of a calcareous deposit precipitated from the waters of the

ancient lake, and described later, which has been named *lithoid tufa.* This, therefore, is called the *Lithoid Terrace.* Its elevation is 500 feet above the 1882 level of Pyramid Lake, which was then 3,783 feet above sea level.

Another chemical deposit, known as *dendritic tufa*, occurs in great quantities in the same basin. At its upper limit it is bounded by a water line, usually but poorly defined, named the *Dendritic Terrace.* Its elevation is 320 feet above the datum plain just mentioned.

Between the Dendritic Terrace and the surface of Pyramid Lake there is a broad platform, which is the strongest and best



Generalized Profile of Lahontan Shores.

defined of all the Lahontan water lines. It marks the upper limit of a third variety of tufa, known as *thinolite*, and is therefore called the *Thinolite Terrace.* Its elevation is about 110 feet above the level of Pyramid Lake in 1882. This terrace has been found to extend entirely around the valleys occupied by Pyramid and Winnemucca lakes, and may also be followed, though less distinctly, about the borders of Black Rock, Smoke Creek, and Carson deserts.

The terraces just named, together with the 1882 level of Pyramid Lake, furnish four definite horizons that will be found convenient reference plains in tracing the Pleistocene history of the basin. It is only at exceptional localities, however, that these terraces can be followed for any considerable distance, and at only a few points could a sequence like the one shown above be obtained. The relative age of the various water lines indicated in the diagram will be discussed when the chemical history of the lake is considered.

The highest terrace of all, the Lahontan, is an inconspicuous feature in itself, but it is important as forming the boundary between subaërial and subaqueous sculpture on the sides of the valleys. It usually appears as a terrace of construction a few feet wide, resting on the broad Lithoid Terrace 30 feet below.

Besides the more definite and strongly marked terraces to which names have been given, there are a large number of less deeply engraved lines on nearly every portion of the former shore. Each of these scorings is the record of a pause in the fluctuations of the water surface. Collectively they indicate numerous changes in the lake level. The obscurity and want of strength in many of them are no doubt due in a great measure to the fact that the slopes on which they were traced have been brought within the reach of wave action many times. In this way the records first made have been erased or obscured by subsequent additions.

Bars and Embankments.—At many localities in the Lahontan basin there are extensive embankments of gravel and sand derived from the cutting of some of the terraces just referred to.

An instructive example of the constructive action of the waves and currents is shown on the map forming Plate IV., of the great gravel embankment now retaining Humboldt Lake. The map referred to is from plane-table surveys made by Mr. Willard D. Johnson of the U. S. Geological Survey, and is so graphic that it requires but little interpretation.

As previously stated, Humboldt Lake owes its existence to the damming of the river tributary to it by extensive gravel embankments which were thrown completely across its channel during the time that Lake Lahontan occupied the valley. The highest level of the ancient water surface is represented on the map by a heavy broken line, and appears in the topography of the country as a gravel embankment, or as a wave-cut terrace at the base of a sea cliff sometimes a hundred feet in height.

The valley in which Humboldt Lake is situated was a strait at the time of the higher stages of Lake Lahontan, and connected the Carson body of the former lake with the waters that occupied the northern part of the Humboldt valley. At a late stage in the ancient lake an embankment of gravel from 50 to 125 feet in height was carried completely across the valley in such a manner as to suggest that it is an artificial structure intended to confine the drainage. At either end the main em-

bankment widens as it approaches the shore, and forms heavy triangular masses of gravel, on the surface of which appear many smaller bars built of clean, well-worn shingle. These secondary bars form ridges with rounded crests, from a few feet to 30 or 40 feet in height, and nearly level-topped for long distances. These are seldom straight, but curve with beautiful symmetry, each gracefully bending ridge marking the course of a current in the waters of the ancient lake in which it was formed.

The embankment crossing the valley declines gently in height from either end toward the center, and has been cut through at its lowest point by the overflow of Humboldt Lake. The gap carved by the outflowing waters is shown in the profile at the bottom of Plate IV. The diagram was constructed from a line of levels run from the Lahontan Beach on the Niter Buttes to the highest water line on the west side of the valley.

At many other localities about the abandoned shores there are fine examples of gravel bars and embankments which show many details, and serve as records of fluctuations and of changes in the direction of the shore currents in the old lake.

Sediments.—The tributaries of lakes, disregarding organic substances, contain two classes of impurities: (*a*) mineral matter in suspension, and (*b*) mineral matter in solution.

Besides holding fine silt in suspension, streams also roll pebbles and stones along their beds. On entering a lake, all this material subsides more or less quickly, forming lake beds, gravel deposits, etc. In the sedimentation of lakes, the coarser and heavier débris is invariably dropped near shore, while the finer and lighter substances are floated to a greater distance before subsiding. In this manner coarse shore and fine offshore deposits originate.

The sedimentary deposits of Lake Lahontan exhibit three definite divisions: viz., upper lacustral clays, from 50 to 75 feet thick; medial gravels, from 50 to 200 feet thick; lower lacustral clays, not fully exposed, but at least 100 feet thick. Wherever any considerable section of Lahontan sediment is seen, these three divisions appear in unvarying sequence.

The upper and lower members of the series are composed of marly clays, which show by their fineness, and the evenness of their lamination, that they were deposited in deep still water. The middle member, on the other hand, usually consists of well-rounded gravel and sand, in some instances becoming coarse,

and including bowlders a foot or more in diameter. This deposit is current-bedded, and exhibits many variations, indicating that it was deposited in shallow water.

The interpretation of this section gives an outline of the later Pleistocene history of the Lahontan basin. There were two high-water periods during which fine clays were deposited. Separating these, there was a time when the lake was low, and allowed current-borne gravels to be carried far out over the previously formed lake beds. During the second flooding especially, the waters underwent long concentration, and at certain stages deposited vast quantities of tufa; during this stage, also, the lake received large quantities of pumiceous dust, thrown out by volcanoes in violent eruption. The second rise of the lake was followed by the present period of desiccation, which witnessed the evaporation of its waters, and the exposure of its sediments to subaërial erosion. The rivers, in flowing across the exposed lake beds, carved the deep channels we have described, and are now spreading stream- and current-borne gravels far out in the central portions of the valleys, thus in many ways repeating the conditions that characterized the time during which the medial gravels were deposited.

The Chemical Records.—Lake Lahontan belonged to the class of inclosed lakes of which the Dead Sea, Caspian Sea, and Great Salt, Mono, Pyramid, Walker, Winnemucca lakes, etc., are existing examples. Lakes of this class are supplied mainly by streams in the same manner as the far more numerous class of lakes with outlets, but the inflow is counterbalanced solely by evaporation.

The waters of streams and springs are never chemically pure, but contain mineral matter, such as carbonate of lime, common salt, etc., in solution. As evaporation takes place from the surface of an inclosed lake to which such waters are contributed, the relative amount of saline matter it holds is increased until the point of saturation for one or more of the contained salts is reached and precipitation begins. Changes of temperature and the vital action of plants and animals may retard or hasten the time when some of the salts begin to be eliminated; but, in general, concentration continues, if the life of the lake is sufficiently prolonged, until the once sweet and wholesome waters become dense brines. In the Dead Sea, for example, the total solids in solution amount to about 24 per cent; that is, about one fourth

the weight of a given volume of the brine is due to material held in solution. Ocean water contains about 3.5 per cent of saline matter. These may be called "standard brines," with which interesting comparisons may be made of the analyses of the water of the present lakes of Nevada already given.

The principal streams tributary to Lake Lahontan occupied the same channels through which Carson, Walker, and Truckee rivers now flow. It is safe to assume that the chemical composition of the waters discharged through these channels at the present time is a fair approximation to the composition of the streams that emptied into the old lake, excepting that, when the precipitation was more abundant than at present, the percentage of saline matter in solution was somewhat less than is now carried. Analyses have shown that the waters at present tributary to the Lahontan basin have about the normal composition of surface streams, which, as found from analyses of a large number of typical rivers in both America and Europe, carry 0.01888 per cent of total solids in solution, of which one half, or 0.00887 per cent, is calcium carbonate (carbonate of lime).

As Lake Lahontan never rose so as to overflow, all of the saline matter carried into it must still remain in its basin.

Calcareous Tufa.—The traveler who crosses the deeper valleys formerly occupied by the waters of Lake Lahontan cannot fail to have his attention attracted by curious and frequently fantastic rock masses, the like of which is seldom seen elsewhere. These strange forms rise from the gray desert like huge mushrooms, or in clustered tower-like structures having a striking resemblance to half-ruined castles. They vary in height from a few feet to fully a hundred feet, and not infrequently are several hundred feet in circumference. Some of the most remarkable of these forms occur about the shores of Pyramid and Winnemucca lakes, or rise from their bottoms, and form unique islands. The general appearance of one of these structures is shown on p. 126. The reader will see at once that these nearly perpendicular towers with rounded dome-shaped summits are not the result of erosion, but still present their original outlines.

These remarkable mushroom-shaped and castle-like forms are composed of calcium carbonate. They owe their origin to the precipitation of the stony matter composing them from the waters of Lake Lahontan. In geological language, this rock is *calcareous tufa.*

On the borders of the deserts that were formerly flooded, and on the hills and buttes rising with them and once existing as islands, there are vast deposits of tufa which sheathe the ancient shores to within thirty feet of the highest beach line. The thickness of this deposit is in some instances upwards of eighty feet.

Tufa Deposits on the Shore of Pyramid Lake.

The total amount of these rocks of chemical origin is astonishingly great, and can only be estimated in millions of tons. In no other known instance is there such a magnificent display of rocks formed by precipitations from lake waters.

If one halts in his journey across the bed of the ancient sea of Nevada, and examines the structure of the tower- and castle-like forms that attract his attention, very interesting facts may be observed.

In some instances the towers have fallen, and sections of their interiors are revealed. It will then be found that they were built up by the successive deposition of layer on layer of stone. When the sections are approximately circular, these layers appear as concentric bands, not unlike the annual rings in the trunk of an oak, but frequently they are several inches and even two or three feet broad. It will also be noticed that three varieties of tufa are present, and that each variety shows many minor subdivisions marked by changes in structure, color, etc. As one proceeds with this examination, the evidence becomes conclusive that even the largest of the water-built castles began by the precipitation of carbonate of lime about a solid nucleus, and grew slowly by the addition of successive layers of the same material. The manner in which these deposits were formed, and the astonishing results attained, show that a great lapse of time was required for the process. The life of the old lake must have embraced at least several thousand years.

The inner core of the tufa towers, and the first layer formed on the sides of the basin, consist of a compact, stony variety of tufa, having in common with the subsequent deposits a yellowish color. On account of its compact texture, this has been called *lithoid tufa.* Its thickness in many instances is from ten to twelve feet; but, as it is usually concealed by both chemical and mechanical deposits of later date, its maximum thickness is probably not known.

Inclosing the lithoid tufa in the towers and castles, and forming a superimposed layer on the first incrustation sheathing the cliffs, is a second variety of tufa composed of rough but well-defined crystals, that are frequently six or eight inches long, and an inch or more in diameter. These crystals are known as *thinolite*, and the name *thinolitic tufa* has been given to the deposit of which they formed the major part. The thickness of this variety is from six to eight feet at its upper limit, and from ten to twelve feet at the lowest horizon exposed.

Succeeding the thinolitic tufa, and forming the most abundant deposit of calcium carbonate in the basin, is a third precipitate of the same general nature as those just mentioned, but having an open, branching structure, and strongly resembling a mass of symmetrically arranged twigs changed to stone, and for this reason named *dendritic tufa.* In many instances this deposit is fully sixty feet in thickness.

The vertical range of these three varieties of tufa varies in an interesting manner. Their limit above the 1882 level of Pyramid Lake is shown in the figure on p. 121, where the horizon of the terrace with which each is associated is indicated.

The lithoid tufa extends up the rocky borders of the valley 500, the thinolitic 110, and the dendritic 320, feet above Pyramid Lake. How much below the level of the lake they may reach is not known, but the domes and islands of the same material rising from its waters have their bases deeply submerged.

The lithoid and thinolitic varieties are thickest at the lowest horizons exposed. The dendritic tufa reaches its greatest development near its upper limit, and frequently hangs from steep cliffs like a massive thatch. In some instances it is so abundant at elevations of from 200 to 300 feet above Pyramid Lake, that it gives a decidedly convex outline to the slopes to which it is attached.

At certain localities on the Carson Desert and about Pyramid Lake the surface of the lake beds partially filling those basins is covered over large areas with polygonal blocks having rounded summits. Each block in these closely set pavements is a mushroom-shaped growth of tufa from ten to twenty inches or more in diameter. These blocks were at first circular in outline, but pressed against one another as they enlarged, and thus received an angular outline, as seen from above.

The base of each separate accumulation of tufa, whether a mushroom-shaped growth a few inches in diameter or a great castle-like form a hundred feet in height and two hundred feet or more in diameter, is a pebble or nucleus of rock about which crystallization began. Wherever there was a solid crag in the old lake suitable for the attachment of the lime precipitated from the water, it became incrusted, and, as the process continued, grew into an imitative form. Detached rocks and islands were especially favorable as centers of accumulation, and became heavily loaded. The borders of the valleys, where composed of solid rock, were also covered, and frequently concealed beneath pendant masses of tufa resembling gigantic honeycombs.

The More Soluble Salts.—As shown by the average composition of river water, about one half of the total solids carried in solution by surface streams is calcium carbonate. This is the most difficult of solution of any of the salts ordinarily found in

such waters, and the first to be precipitated when concentration by evaporation takes place. The more soluble salts consist mainly of sodium sulphate, sodium carbonate or bicarbonate, sodium chloride, silica, magnesium, potash, iron, etc.

The amount of these more soluble substances carried into Lake Lahontan must therefore have been about equal to the amount of calcareous tufa precipitated. As the lake never overflowed, these salts must still exist in its now nearly desiccated basin; yet, in riding through the valleys that were formerly flooded, no deposits of the salts referred to can be found, at all commensurate with the vast quantity of calcium carbonate that attracts one's attention. The disappearance of the salts referred to seems to be satisfactorily explained in the following hypothesis: —

After the last great rise of Lake Lahontan, there was a long-continued episode during which its basin was more arid than at present. Evaporation during that time is thought to have been equal to precipitation, and the residual lakes were reduced to the playa condition; that is, the remnants of the great lake gathered in the lowest depressions of its basin were annually or occasionally evaporated to dryness, and their contained salts were precipitated, and either absorbed by the clays, etc., deposited at the same time, or buried beneath such mechanical deposits. This process may be observed in action in many of the valleys of Nevada in which ephemeral lakes occur. The broad, naked playas of Black Rock, Smoke Creek, and Carson deserts, as well as the level floors of the basins occupied by Pyramid, Winnemucca, and Walker lakes, are in support of this hypothesis. Should the lakes just mentioned be evaporated to dryness, playas would be left similar to those in neighboring valleys of less depth. It is beneath the level floors of these valleys and lake basins that the more soluble salts once dissolved in the waters of Lake Lahontan are buried. Borings at certain localities might reveal the presence of strata of various salts, but in most cases they are probably disseminated through great thicknesses of clay, sand, and other mechanical sediments.

Analyses of the stratified beds laid down in the basin of Lake Lahontan show that they are charged with saline matter to such an extent, that the total quantity of the various soluble salts contained in them is certainly equal to, and probably in excess of, the calcareous tufa now visible in the same depressions.

THE ORGANIC RECORDS.—The evidence derived from organic remains indicates that Lake Lahontan throughout its higher stages was never a strong saline or alkaline solution. Even during the abundant precipitation of dendritic tufa, the lake was inhabited by mollusks in great numbers, and was probably also the home of fishes of large size. During the thinolitic stage, when its waters were greatly concentrated by evaporation, the absence of fossils indicates that it was uninhabited by either fishes or mollusks.

SUMMARY OF THE HISTORY OF LAKE LAHONTAN.—The combined results of a somewhat extended study of the physical, chemical, organic, and other records left by Lake Lahontan, show that it furnishes a typical illustration of the life history of an inclosed lake. The marked difference in the destiny of a lake that never finds an outlet, from the changes experienced by a normal lake, may be strikingly illustrated by contrasting the history of the Lahontan basin with that of a similar basin in a humid region which has been filled to overflowing, and been drained or filled, and transferred into a terraced valley.

Lake Lahontan began with the expansion of several playa lakes in the lowest depressions of its composite basin. These rose, with many fluctuations, until they became united, and continued to increase in depth and extent until the full expansion of the first maximum was reached. This growth was due to a climatic change which caused an increase in precipitation and an accompanying decrease in evaporation. Glaciers existed on the higher portion of the Sierra Nevada and on some of the basin ranges to the east, and by their melting assisted in the flooding of adjacent valleys. Then came a time of aridity. The previously flooded valleys became as waterless as at present, and possibly were completely desiccated. A second period of increased humidity caused the basin to be again partially filled. The waters rose 110 feet above the level of Pyramid Lake, and the thinolitic tufa was precipitated from it. The character of this deposit indicates that a chemical change had taken place in the lake water. What this change was is not clearly understood.

After the crystallization of thinolite had gone on for a long period, the lake rose 210 feet, or to within 280 feet of its first maximum; and the heaviest of all the tufa deposits, the dendritic variety, was precipitated. After the greater part of this variety of tufa had been formed, the lake continued to rise, and

at length reached an horizon 30 feet higher than at the time of its first great expansion. At the highest stage the water lingered but a short time, and no chemical precipitates remain to record it. Two terraces, or, in other localities, two embankments of gravel resting on the lithoid terrace, were formed during this second rise. An increase in depth after the deposition of the major part of the dendritic tufa is shown by the presence of fine mechanical sediments resting on it.

The recession of the waters after the second rise brought all portions of the basin previously submerged within the reach of waves and currents, and the sheathings of tufa were in part cut away, and their fragments built into embankments and terraces.

The waters continued to fall, with many fluctuations, until the basin was completely dry. All of the salts not previously precipitated were deposited as desiccation advanced, and became buried or absorbed by playa clays.

The duration of the post-Lahontan period of desiccation is unknown, but judging from the length of time that would be required for Pyramid, Winnemucca, and Walker lakes to acquire their present degree of salinity under existing conditions, it must have closed about three hundred years since.

Throughout its entire history the lake underwent a multitude of minor oscillations. These are imperfectly recorded by a large number of indefinite terraces, and by a multitude of narrow bands of varying structure in the tufa deposit.

The main features in the fluctuations of Lake Lahontan coincide in a remarkable way with the history of Lake Bonneville, and show that the climatic changes to which they were due were not local. It is assumed, for what seem valid reasons, that the two high-water stages recorded in each of these lakes were synchronous with two periods of ice extension over northeastern North America during the glacier period. If this correlation proves to be well founded,—and at present there is no reason to doubt its validity,—it will show a still wider extent in the climatic changes that have affected the lakes of Nevada.

Interpretation of the Records in Terms of Climate.—In regions where the mean annual rainfall on a given area exceeds the mean annual evaporation, it is manifest that an inclosed lake cannot long exist. No matter how deep the basin, it must ultimately be filled to overflowing. The study of the present geography of the earth shows, that, in regions where the

mean annual precipitation exceeds about twenty or perhaps twenty-five inches, inclosed lakes do not occur, although the topographic conditions may be favorable.

These and other considerations lead to the conclusion that the climatic changes which led to the flooding of the Lahontan basin, but did not permit its becoming filled to overflowing, were not accompanied by heavy rainfall; and that the mean annual precipitation throughout its history was less than twenty or twenty-five inches.

Remembering that the principal streams flowing to Lake Lahontan came from the high mountains on its western border, and that at the time of its greatest expansion its water surface was less than one quarter of its catchment area, and also that evaporation probably decreased as the rainfall increased, it seems safe to assume that the average rainfall over Nevada at the time it was transformed into a lake region was probably not in excess of ten or fifteen inches a year.

Considering the question of humidity alone, the times of marked expansion in the ancient lakes of the Great Basin indicate an increase in mean annual precipitation, and times of contracted water surface a decrease in rainfall. Thus interpreted, we have two periods of increased rainfall and of relatively great humidity, separated by an inter-lacustral arid period. The first period of precipitation was preceded by an arid period; and a similar period succeeded the last rise, and continues to the present day.

The sediments of lakes more ancient than those just described, and containing the bones of many extinct animals and the leaves of a luxuriant flora, also occur in Nevada; but of this older chapter in the earth's history, space will not permit me to speak.

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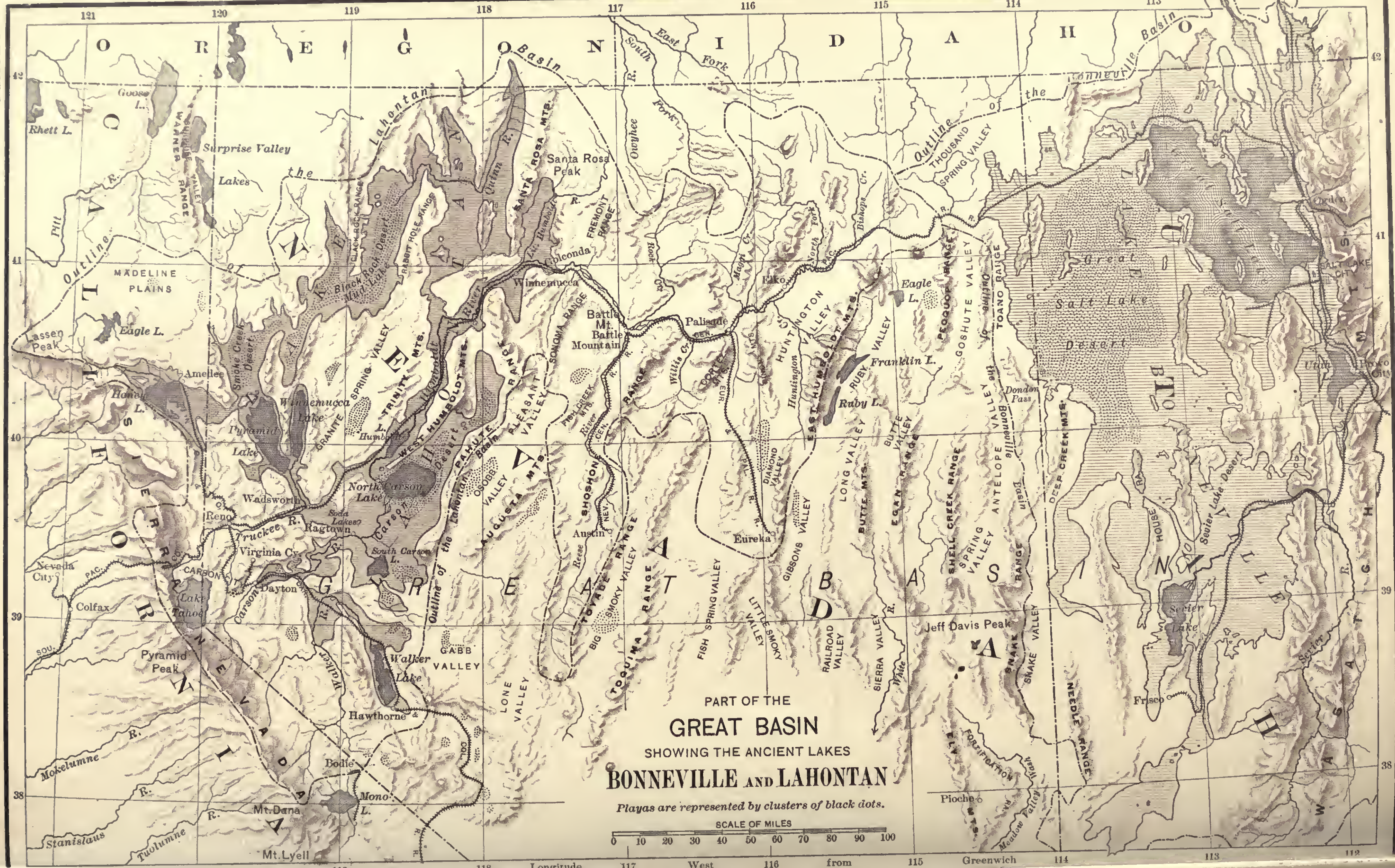

PART OF THE
GREAT BASIN
SHOWING THE ANCIENT LAKES
BONNEVILLE AND LAHONTAN
Playas are represented by clusters of black dots.
SCALE OF MILES
0 10 20 30 40 50 60 70 80 90 100
Longitude West from Greenwich
OREGON
IDAHO
UTAH
CALIFORNIA
SIERRA NEVADA
NEVADA
GREAT BASIN
LAKE LAHONTAN
LAKE BONNEVILLE
WASATCH MTS.
Outline of the Lahontan Basin
Outline of the Bonneville Basin
Rhett L.
Goose L.
Pitt R.
Surprise Valley
Lakes
WARNER RANGE
MADELINE PLAINS
Eagle L.
Lassen Peak
Honey L.
Amedee
Smoke Creek Desert
Pyramid Lake
Winnemucca Lake
Black Rock Desert
Mud Lake
BLACK ROCK RANGE
RABBIT HOLE RANGE
Quinn R.
SANTA ROSA MTS.
Santa Rosa Peak
Lit. Humboldt R.
FREMONT RANGE
Golconda
Winnemucca
Humboldt River
GRANITE SPRING VALLEY
TRINITY MTS.
Humboldt L.
WEST HUMBOLDT MTS.
Humboldt Desert
PAHUTE RANGE
PLEASANT VALLEY
SONOMA RANGE
Battle Mt.
Battle Mountain
North Carson Lake
Carson Desert
Soda Lakes
Ragtown
South Carson L.
Wadsworth
Reno
Truckee R.
Virginia Cy.
Nevada City
Colfax
CARSON
Lake Tahoe
Carson R.
Dayton
Walker R.
Walker Lake
GABB VALLEY
Hawthorne
Bodie
Mono L.
Mt. Dana
Mt. Lyell
Pyramid Peak
Mokelumne R.
Stanislaus
Tuolumne R.
OSOBB VALLEY
AUGUSTA MTS.
LONE VALLEY
FISH CREEK MTS.
Reese River
SHOSHONE RANGE
Austin
TOYABE RANGE
BIG SMOKY VALLEY
TOQUIMA RANGE
FISH SPRING VALLEY
LITTLE SMOKY VALLEY
Owyhee R.
South Fork
East Fork
Rock Cr.
Willis Cr.
Palisade
CORTEZ MTS.
Eureka
DIAMOND VALLEY
GIBSONS VALLEY
RAILROAD VALLEY
Maggi Cr.
Elko
North Fork
Bishops Cr.
HUNTINGTON VALLEY
Huntington
EAST HUMBOLDT MTS.
Ruby L.
Franklin L.
RUBY VALLEY
LONG VALLEY
BUTTE MTS.
BUTTE VALLEY
EGAN RANGE
SIERRA VALLEY
White R.
Eagle L.
PEOQUOP RANGE
GOSHUTE VALLEY
THOUSAND SPRING VALLEY
TOANO RANGE
Dondon Pass
SHELL CREEK RANGE
SPRING VALLEY
ANTELOPE VALLEY
SNAKE RANGE
SNAKE VALLEY
Jeff Davis Peak
ELY MTS.
FORTIFICATION RA.
Meadow Valley Wash
Pioche
DEEP CREEK MTS.
Great Salt Lake Desert
HOUSE RA.
Sevier Lake Desert
Sevier Lake
Sevier R.
Frisco
NEEDLE RANGE
Ogden
SALT LAKE CITY
Utah L.
Provo City

PLATE II

119° 45'
119°30'
119°
40° 15
40°
Terrace Pt.
The Needles
PYRAMID LAKE
LAKE RANGE
Tohakum Pk.
WINNEMUCCA LAKE
NACHE RANGE
Nache Pk.
VIRGINIA RANGE
Pyramid I.
Anaho I.
Mullen's Gap
Marble Buttes
Truckee River
50
100
150
200
250
300
350
80
82
87
85
81
Lahontan Beach
Sub-Lacustral Contours
Soundings in feet.
SCALE OF MILES
0 1 2 3 4 5 6 7 8 9 10

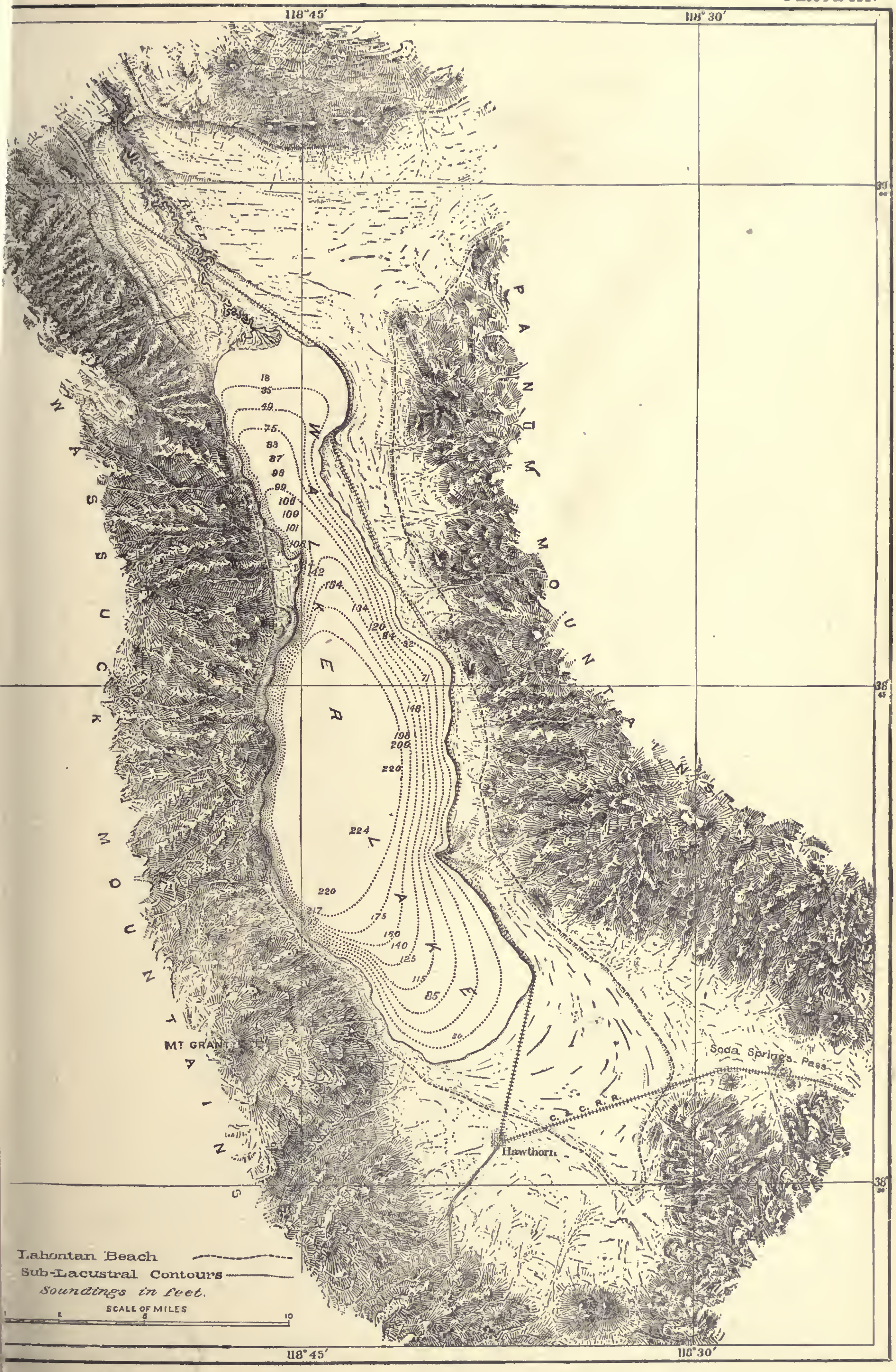
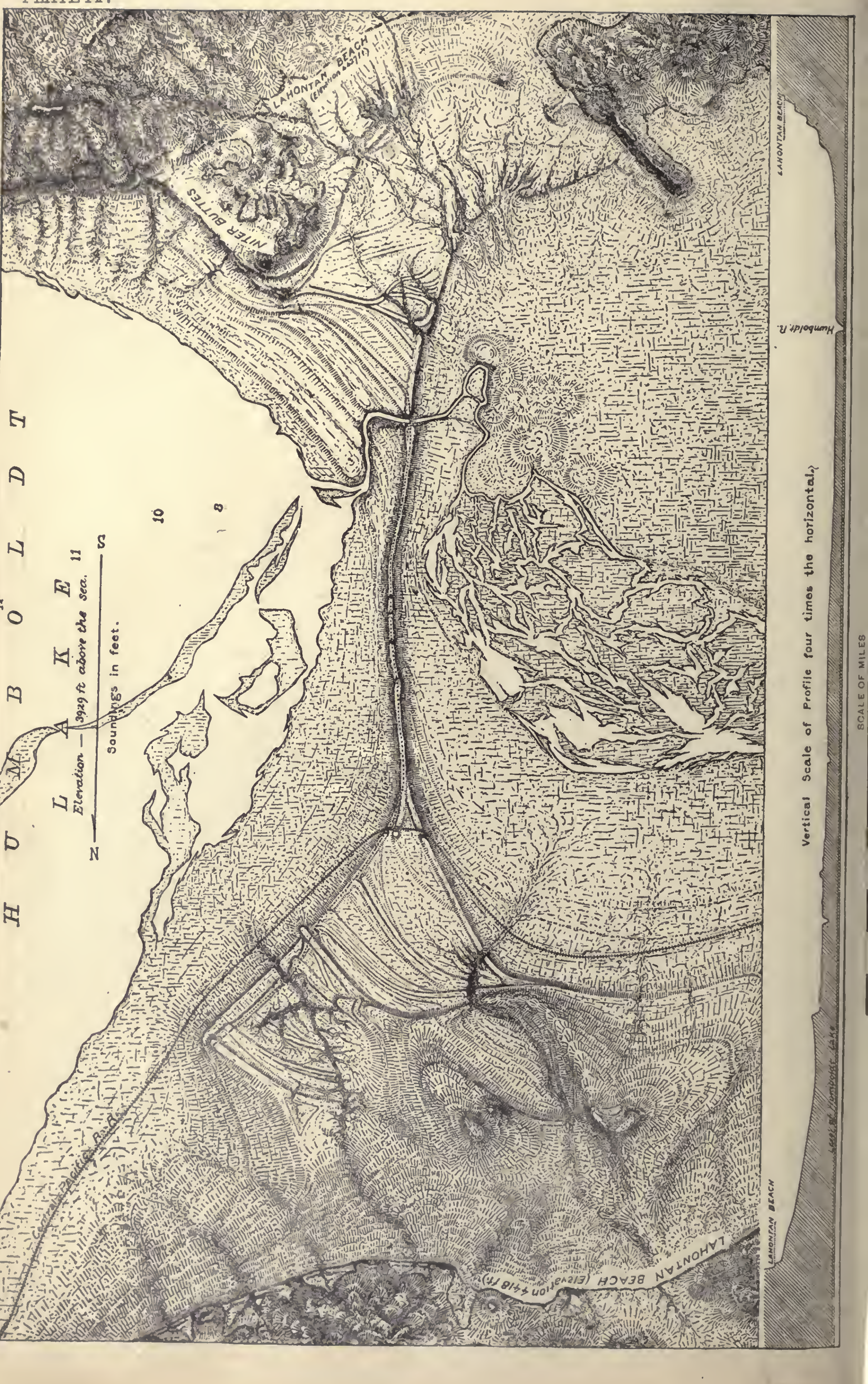

118°45'
118°30'
River
WASSUCK MOUNTAINS
WALKER LAKE
Mt GRANT
Soda Springs Pass
C. & C. R.R.
Hawthorn
Lahontan Beach
Sub-Lacustral Contours
Soundings in feet.
SCALE OF MILES
118°45'
118°30'

PLATE IV.


HUMBOLDT LAKE
Elevation — 3929 ft above the sea.
Soundings in feet.
N
S
12
11
10
8
NITER BUTTES
LAHONTAN BEACH
LAHONTAN BEACH (Elevation 4418 ft.)
Humboldt R.
Vertical Scale of Profile four times the horizontal.
LAHONTAN BEACH
LAHONTAN BEACH
SCALE OF MILES

BEACHES AND TIDAL MARSHES OF THE ATLANTIC COAST.

By N. S. Shaler.

Introduction.—The essence of modern science, the quality which the beginner in its study needs above all else to master, is the habit of patiently seeking to disentangle the maze of nature, so that he may be able to trace the orderly associations of events in what seems, to the ordinary view at least, a picturesque jumble of unrelated facts. To do this task in an effective way, the student should take up some class of actions in which he may trace the phenomena from one step of their growth to another, until he sees how they fit into the system of this earth. For such a task there is perhaps no matter which better lends itself to his needs than that of beaches. The features with which we here have to deal are tolerably well exhibited on a greater or less scale in all parts of the world which are not actual deserts. They are traceable along the shores of tiny pools and rivulets; many of them are nearly as well shown in the smaller as in the larger examples; and certain of the more important of them can be more easily studied in the instances afforded by an artificial pool than on the shores of the ocean. In these little examples we may behold in a very limited compass many of the processes by which the land was formed and destroyed, or rather, we should say, made over, by the ceaselessly acting agents which change the shape of the earth's surface.

To obtain the first preliminary notion of what a beach means, the student should choose some place on the margin of the sea, or, better, on the shores of a pond or river, where soft materials, such as beds of sand and gravel, are subjected to the action of

the waves. Selecting a time when the wind is blowing toward the shore, he may note that the waves strike the bank with a certain amount of force, and that the incoherent rocky matter crumbles under their action. Partly by the stroke of the waves, and partly by the dissolving effect of the water, the earthy material slips down the cliff, and is usually distributed over a gentle slope extending downward and outward from its base. In this simple group of facts we see the leading principles of beach action, which is, that materials which are brought into a water basin are so arranged that they tend to form a sloping mass of débris, the higher part of the incline being next the cliff. We may indeed define a beach as a mass of detritus which has been brought into its position by the operation of waves, more or less assisted in their work by current action. As we shall see, however, this general statement has to be extended and qualified, in order that it may be made to fit the numberless special groups of beaches which the varied conditions of this world bring about.

The student of beach phenomena may well begin his observations with the conditions which he will find set before him in the little rivulets in which are first gathered the waters of a river system. This field of action is particularly well fitted to show the relation of beaches to the other work which is done by the agency of water. In all head-water streams it is easy to see how rock materials, worn away from their bed places by the action of frost and the other agents of decay, are brought, at times of heavy rain, to the channels of the streams, and thus placed where they may be borne gradually downward to the ocean. Watching any one of these rivulets when it is swollen by the rainfall, we readily note that in the middle of the channel, where the water is deepest, the débris moves along with much greater rapidity than it does in the shallower portions of the current next the banks, and that the fragments which are traveling in this central part of the streamlet are generally much larger than those which are in the part of the procession near the shore. Where the brook is perhaps ten feet wide and three feet deep in the middle, shallowing gradually toward the banks, the deeper water carries onward pebbles several inches in diameter, or, if the bed be steep, it may urge forward bowlders a foot or two in cross section; yet toward the sides of the torrent, where the depth is only three or four inches, the stream is seen to carry only small pebbles, while in the shallowest fringe of water

nothing but the fine sand is in motion. As this difference in the energy of stream action is not only curious, but of great consequence in the history of the earth, we must look closely to its origin and effects.

It is well known that bodies weigh less in water or other fluids than in the air. This buoyancy, as it is called, is what causes wood or even porous stone, as pumice, to float. A simple experiment of this principle can be made by lifting a stone with the hand out of a basin of water. As long as it is submerged it weighs much less than it does when it is above the level of the fluid. The result of this is that all rock material is much more easily trundled along the stream beds than in the open air. Next we have to note the fact that the downward shoving power of water increases at a singularly rapid rate with the acceleration of its speed. Therefore the speed with which water moves, profoundly affects the value of the work which it can perform.

We have now to note that the velocity with which a current or stream of water moves depends in a very important and immediate way on its depth, which depth determines the retarding effects of the friction of the fluid on its bottom. Returning to the case of the brook, we readily perceive that the stream is flowing several times as fast in its middle part, where the water is deep, as next the shore, where it is shallow. A closer study will show that the speed of motion is directly proportional to the depth, and that the current is everywhere swifter on or near the surface than it is next the bottom.

River Beaches.—We are now in a position to see how river beaches are formed and maintained by the action of the running water. The detritus which, especially in times of heavy rain, is swept into these channels from the steep hillsides, journeys on as best it may in the varying conditions of the current. The larger stones generally keep in the deeper part of the water, being led there by the sloping sides of the channel. The fine stuff is often whirled by the eddies into the shallow parts next the banks, into portions of the bed where, because of the friction which the current encounters in moving over the bottom, the flow is less speedy. Attaining a depth where the little waves which the winds create can affect them, the particles of sand and gravel are at once arranged in the form of a beach; that is, in the gently curved slope, with its higher part lying against

the banks which confine the water. In the production of this beach the principles which regulate current movements, and the transportation of the sediments that they carry, again control the action. To see how this is effected, we must now attend to the curious movements which take place in wave motion. Although it is easiest to study the features of waves on the shore of a large expanse of water, a great lake or the ocean, all that we now need in the way of information may be had by closely observing the wavelets of a brook or small river, which are formed when a strong wind is blowing across the water. By noting the motion of any floating bits of wood, we perceive that the wave is an undulation of the water essentially like that we see in a sheet of cloth when it is shaken by the hand or by the wind; in other words, the wave moves on, though the particles of matter through which it passes do not go forward. When the water is, say, ten times as deep as the wave is high, it sweeps over the bottom without much effect; but when the water is relatively shallow, it sets the finer grains of sand in motion in the direction in which it is traveling, each wave bobbing them along for a short distance as it passes by. As the undulation comes into shoaler water, it rubs upon the bottom with energy, which increases with the shoaling; so that next the shore it commonly has sufficient power to drag a good deal of sand with it. In this manner the greater part of the sand of river beaches is taken from the deeper parts of the stream and carried against the shore.

Some parts of the sand of river beaches are swung out of the channel by eddies. Those whirling motions of the waters tend to throw sand or even light pebbles to their borders, and so bring detritus against the bank or into shallow water, where the waves may be able to move it. Again, in the banks of the larger streams there is commonly a mass of alluvium or débris which the river has at former times brought down and built into a plain, through which the stream now wanders. We may readily see that this plain is generally forming on one side, and cutting away on the other. As the bank is undermined on the wasting side, the sand and gravel which are given to the stream are generally built for a time into a beach a little way below the point where they are committed to the current.

It is characteristic of the sand in river beaches, as we shall find it to be also of that in sea beaches in general, that it is

usually in tolerably constant motion, the particles journeying slowly downstream. Each time the waves stir the grains of sand, the latter move a little distance on their way to the sea. At every season of floods, the deposit, being covered by deep and swift-moving water, is destroyed or greatly diminished in mass, to be again developed when for a considerable period the water remains at nearly one level. In fact, all the débris in a brook or river is normally in a condition of downward movement, which is only for a time interrupted by low water, when for a season the stream takes on a character of separate pool-like areas of water separated from each other by rapids. It is during these periods of relative stagnation of the current, when each pool is much like a small sea, that distinct beaches are formed. Their presence, indeed, may be taken as an indication that the river is at its low stage of flow. Imperfect and temporary as are the beaches beside the streams, they serve to show the usual conditions of contact of land and water, so that the student who is denied access to the nobler instances of such structures on the margins of the seas or lakes may well use them for his inquiries.

Sea and Lake Beaches.—Turning from the rivers, where the beaches are only incidental phenomena in the work of water, we shall now consider the shore work in the seas and lakes, where those features are almost everywhere to be noted. In these basins, where the water, except for the swing of the tides, commonly remains without appreciable change of level for centuries or for thousands of years, there has usually been time for débris to gather along the shores in such quantities that it affords the foundation for a beach. Here and there along the coast we find where the land, having been carved into steeps by the action of streams or glaciers, has then by a downsinking process been brought below the sea level at so recent a period that the destruction of the cliffs aided by the action of the waves has not yet sufficed to fill the sea at their base so as to form a beach. Again it happens, particularly about the North Atlantic, that the glaciers of the last ice time swept far out to sea beyond the shore line, destroying the ancient beaches; so that when the frozen waters melted, the sea level came again against steeps, forming deep water at their base. That this is an exceptional, indeed we may say a temporary, condition of the contact of sea and land,—one which is everywhere in process of being over-

come,—can readily be seen by any one who will watch such a shore during a time of heavy storm.

Approaching in a time of storm a rock-bound coast, where the cliffs descend into deep water, the observer may, from some projecting headland, look along the shore so as to behold the majestic spectacle which the surges afford as they rush against the shore. Four or five times a minute the waves, having a height of maybe twenty or thirty feet, charge against the rampart, and break into spray and foam as they meet the steep. Where the rock is firm-set and smooth, the blows have no distinct effect; but wherever there is a weak place in the defenses, the waves have hollowed out a recess, which may be a considerable cave, into which the swift-moving water rushes with a fury which is intensified by the narrowing space of the channel. In such a recess the waves generally find some bits of stone, which they swing against the walls, thus deepening and widening the recess. In time the overhanging rock falls down, thus serving to shallow the water at the base of the cliffs. This quarrying work is aided by the action of frost and other agents of decay, which are constantly at work on the face and summit of the precipices. Each year a quantity of débris is added to the heap which lies under the water. In this accumulation of rocky matter there enters a large amount of organic waste, the hard parts left at the death of various shell-bearing animals, such as abound on the bottom of the sea near the land. In this way a steeply sloping mass is built up, which in time has its upper part so near the surface of the water that the fragments of which it is composed may be moved by the waves.

When the submarine talus at the foot of an ocean cliff has attained an elevation which permits the waves effectively to act upon it, a true beach is speedily formed. As soon as the masses of stone are in a position to be tossed about by the surges, they are thrown in times of storm against the base of the cliff. We may often hear the sound of the blows they deliver, adding a harsh, crashing note to the roar of the breakers. The effect of this work is soon marked in the rounded form of the stones and in the excavation which has been made as a continuous indentation at the foot of the cliffs which thus are made to overhang. In this condition the destruction of the hardest and firmest kind of rocks goes on at a rapid rate, for gravity now aids the other powers of waste in a most effective manner. From

time to time masses from the jutting face fall to the level of the sea. Generally, in falling, they break into bits small enough to be tossed about by the greater waves, and so in time serve as battering instruments for the further assault of the land. The complexity of this erosive work is great (a volume could be written about it); but enough has been said to show how effectively the land may be worn when there is a chance for the waves to hurl stones against its steep seaward faces.

Rolling Beaches.—As the further construction of the young beach proceeds, the mass of débris widens, and its slope to the seaward becomes more gentle, until it finally forms a rather wide strand having a slope of not more than ten degrees' declivity. Where the sea floor was originally level up to the base of the crags, there is now a talus sloping from the level of the high tide to the distance of, it may be, half a mile outward. As this talus gains in width, it serves to protect the cliffs against the blows of the waves. Only those of greater storms now attack the firm rock; the surges of ordinary times spend their forces on the bowldery and pebbly matter. At this stage the accumulation of detritus, or at least the upper part of it, becomes a *rolling beach*,—a curious and most important mill, in which stone is ground to the state of sand and mud.

If the student desires to see the rolling beaches in operation, he must visit the shore when there is a strong wind blowing upon the coast. An inspection made in good weather will not give the desired lesson, for the light waves of such a time do not suffice to set the mill in motion. When the seas break with their fronts ten feet or more in height, they strike a blow strong enough to send to and fro rounded fragments of rock which are three or four feet in diameter. With the advance of the waves these bowlders are driven up the beach. If the seas are powerful enough, the pebbles may be dashed against the cliff whence they came; more often they roll up and down until they are worn out. In times of storm the stones of a rolling beach, sometimes to the depth of two or three feet, are carried to and fro with the advance and retreat of the waves. In this movement the bits roll over one another much in the manner of millstones. The softer are rapidly ground to the state of sand or mud, in which state the waste is readily carried away by the currents to the open sea.

Although a large part of the pebbles which are found on

any bowlder beach have made their way along the shore from promontories where the fragments are broken off by the waves, another and perhaps more considerable part of these stones is brought in from the sea bottom by the action of various marine plants. Wherever the sea floor next the shore and in shallow water is strewn with pebbles derived from ancient glaciers, or perhaps formed on beaches which now lie below the surface of the water, seaweed becomes attached to these fragments of rock, finding their surfaces convenient places on which to fix its rootlike attachments. Almost all these species are provided with air vesicles, which serve to keep their stems and branches upright: therefore when they become large, they exercise a certain pulling action on the stones; and the waves, as they pass by, pull upon the surfaces of the plant. The result is that in time of storm the stone is lifted above the bottom and borne toward the beach. A few strokes of the waves serve to detach the plant, after which the pebble becomes a part of the rolling beach, whereon it is in time ground to powder.

Many of the pebbly beaches in New England are entirely supplied by the action of seaweeds; and one small island near the coast of Cape Ann, which is no more than a rolling beach washed by the waves, appears to be maintained by the constant importation of pebbles which are plucked from the bottom in the manner above described. The same process, with shells taking the place of pebbles, may be traced along the sandy shores of all the continents. In fact, the greater part of the shells found on some of the Atlantic sand beaches which have been studied by the writer owe their transportation from the bottom to the strand to the action of seaweeds, or, in some cases, to the similar effect exercised by the growth of plant-like animals, such as sertularians, which have become attached to the hard parts of the mollusks.

Action of Waves and Tides in the Formation of Beaches.— The energy of the sun sets the air in motion, and the wind causes the waves, so that it is solar force which is imparted to the waves. Moving over the deeper parts of the sea, these undulations have probably no effect on the bottom. As the wave comes nearer the shore, and enters the shallowest parts of the sea, it begins to drag on the bottom. This action is not considerable until the depth is less than two hundred feet, where the ordinarily great wave is competent to move sand up the slope toward the shore. As the water still further shallows, the scraping movement

increases, until it can move at first the smaller pebbles, and at last the bowlders of great weight. The result of this action is that the waves which roll on a shore are effective in moving fragments from a considerable depth to the strand. If this were the only source of motion along the coast, the effect would be to heap up a great mass of débris at about the level of high tide. There are, however, as we shall now see, many other influences at work which have a large share in determining the form of a beach.

Moving over the deep sea, a wave proceeds as an oscillation or wrinkle of the water, which is substantially, as before noted, like the undulations of a shaken cloth. Only in a very small measure does the water go forward in the direction in which the wave is moving. When, however, the surge comes into shallow water, its form and the character of its motion undergo important changes, which progress with the shoaling. The wave shortens up, becoming relatively higher and steeper; it also imparts a stronger forward movement to the water. The shortening and steepening of the wave is brought about in the following manner: Coming ever into shallower water as it nears the shore, the surge finds the friction due to the bottom greatest in its front part: this part is therefore proportionately more retarded than the following portion of the swell, which thus tends to overtake the front. As water is practically imcompressible, the wave has to increase in height. This principle, which is called the *conservation of areas*, can well be illustrated by flexing a piece of paper, pushing the arch over a table, and shortening the base as it nears an imaginary shore line.

An interesting coöperative work in the action of waves and tides is effected through a peculiar movement of the sea known as the *undertow*. When the waves roll heavily in upon a shelving coast, a considerable amount of water contained in the upper part of the surges moves in upon the shore more rapidly than that in the under part of the wave. This incoming water, having to escape eventually seaward, finds its way out along the bottom. Those who are accustomed to swim along the coast where the bottom is shallow, and at times when the surf is heavy, have often found themselves drawn away from the land by this undercurrent. It may well be noted that the stream never affects the upper two feet or so of the sea, and rarely has strength save below the level of three feet. Thus a swimmer who takes pains

in his movements that no part of his body is deeply immersed can readily make his way back to the land.

The effect of the undertow, which is strongest when the waves are attacking the shore with the greatest energy, is to draw the fine sediments away from the immediate coast line, bringing the detritus far enough out to sea for it to be taken by the tidal currents, which convey it, it may be, for many miles away from the coast line.

If a wave suffered no other change as it approached a shore save that due to the shortening of its width, the result would be the formation of surges of vast height, which would strike upon the coast line with many times the energy which they actually possess. The fact is, that as soon as the wave arrives in water sufficiently shallow to hinder its forward motion, and thus to bring about the increase in height, the friction which it encounters progressively tends to exhaust the energy which is stored in the undulation. In the existing conditions of our coast lines, probably the greater part of the energy of the waves is applied to the bottom of the shallows which they traverse before they attain the beaches or cliffs. In these shallows they impel the detritus up the slope, and cast it upon the shore. If this action were not opposed by the work of the tides, the effect would be to greatly increase the amount of sand and fine pebbles which we find at the contact of sea and land; but the work of the tidal oscillation is distinctly to hinder and limit the invasion of sand from the continental shelf.

As the tidal wave rushes in upon a coast, it has, when it comes from the deeper sea, a rate of advance of several hundred miles per hour; but, owing to the slight amount of elevation which it gives to the waters, it exercises at first only a small dragging power on the detritus of the ocean floor. The nearer it comes to the shore, the greater this dragging action, because of the shallowing of the water; but the effect is rarely great enough to move more than coarse sand or small pebbles. As the tide comes toward the land, these movable fragments are carried up the slope which leads to the shore. As the tidal wave goes out, the bits journey away from the coast. It is easy to see that, as the movement takes place up and down the sloping floor of the sea, the effect will be to carry the sand and pebbles farther and farther from the shore, and this for the reason that they will move farther with a given tidal impulse in the direc-

tion in which the bottom inclines. In this way the tides, by dragging materials from the beaches and shallows toward the deep sea, serve ever to extend the continental shelf.

The action of waves and tides on the sands of the shallow waters, though in general of a contrasted nature, is not uniformly so. The surges act only in times when gales blow upon the coast; while the swingings of the water which are due to the attraction of sun and moon operate with something like uniformity, varying only as these planetary bodies unite or oppose their influences at the periods of spring or neap tides. The general effect of these combined actions is to make the amount of sand which is gathered on any beach from time to time quite variable.

Action of the Wind in the Formation of Beaches.—There is yet another cause of much diversity in the amount of sand which we may find upon a beach. This is due to the action of the wind. So long as the débris along the coast is covered with water, the wind can act upon it only by means of the waves or currents which it induces in the fluid; when, however, the sand is bared by the retreating tide, it quickly dries, and in this state is easily moved about by the air streams when they have a considerable speed. Blowing upon the shore, the winds carry the sand, and even small pebbles, from the stretch of surface between high and low tides above and beyond the verge of the waters, usually accumulating the material in the heaps known as *dunes*. When the wind blows offshore, as it prevailingly does along the Atlantic coast of North America, it carries the dry sand back into the sea, where, if the conditions favor, it may be removed by the tidal and other currents to a distance from the land. In this way the accumulations of sand on beaches along the eastern coast of the United States are much restricted. Where the prevailing winds come in upon shores which are bordered by sand beaches, sand dunes always abound. These accumulations are indeed accurate gauges of the average direction of the winds which are strong enough to move sand. In their slighter forms sand dunes are inconspicuous, but where they are well developed they afford some of the most striking features which are found at the contact line of sea and land. They are, moreover, in certain cases, of no small importance in the history of the shore lands. We shall therefore note some of their more important features.

SAND DUNES.—When the sand is driven up the slope of a beach to a point beyond the high-water level, it at once escapes from the field in which it was subjected to the forming and uniforming actions which make the grains and dispose them on the smooth incline of the shore. When the wind-blown fragments come to the top of the beach, they encounter a relatively rough surface on which there are usually abundant tussocks of rough grass or of other plants; these diminish the energy of the wind, which on the more open shore had full sweep, and so serve to bring the grains of sand to rest. As soon as a little heap is thus formed, it affords a yet better shelter on its landward side, and so gives the essential conditions for the growth of a dune. Thenceforth the process is very simple: the flying bits move up the seaward face of the mound, slip over its summit, and come to rest on the leeward face of the elevation. As the sand, even when it appears very barren, contains much food for plants, many species have become specially modified to support life in the difficult conditions which the dunes afford. The most of these plants belong in the groups of grasses, of which the well-known *beach grass* is the most widely distributed and best-known form. This interesting species has very long and strong-growing roots, which enable it to seek a supply of water, as the plants have to do, at a great depth below the surface. Its leaves are remarkably tough, and are thus fitted to withstand the rude treatment of the storm winds. This plant, like others of its kindred, but in a yet more efficient way, increases not only by its seed, but by means of runners or horizontally extended roots, which grow with such rapidity that they may extend for the distance of ten feet or more in a year. From point to point these runners give off vertical shoots, which establish the crown of a new plant; these horizontally disposed roots also put forth a great number of fibrils, which enmesh the sand so as to make it difficult for the strongest blast to disturb the mass.

On account of the vegetation which occupies the top of a dune, a considerable store of the sand which is driven upon the hill is held upon the summit: the elevation thus grows in height. This growth may go on until the mass rises a hundred feet or more above the level of its base, while its width and length may be several times as great. As the conditions which determine the formation of these curious products of the beaches are peculiar and irregular, the slopes and arrangements of dune hills at

first sight appear to be more disorderly than is the case with any other groups of shore features. This apparently confused nature of dunes is in great part due to the fact that they alone, of all the elevations of the land, have the singular habit of marching away from their point of origin, it may be for great distances across the country.

On the seaward side of the dune, because of the energy of the wind, at times when storms blow upon the coast, the blast digs the dry sand from among the roots of the vegetation, and sends the uprooted plants and sand together over the top of the hill to its landward side. So rapidly does this process go on, that in a single protracted gale a dune thirty feet high may be moved back from the shore for a distance of fifty feet or more. As the marching mass of sand journeys away from the coast, various causes serve to restrain its movement. It is ever coming into districts where the air moves less swiftly. As the grains of sand decay, they begin to cement together,—a process which directly hinders the work of the wind and favors the growth of plants: hence it comes about that the advance of a dune is gradually slowed, and in the end the dune comes to rest. Yet in some cases they have been observed to journey for as much as ten miles from the beaches next which they were formed. In some instances they have overwhelmed villages and desolated extensive tracts of fertile land.

It not infrequently happens that dunes of considerable size form on the shores of fresh-water lakes. Thus some of the most important of these wind-blown hills in this country lie at the southern end of Lake Michigan. In such cases we always find that the sand is derived from the moving of beds of a sandy nature, which are broken up by the waves. In yet other and rarer instances, dunes form along the banks of rivers where the alluvial cliffs are sufficiently sandy to afford a considerable supply of fine detritus to the winds. As these fluviatile dunes cannot ordinarily go far before they enter fields thickly covered with vegetation, they rarely wander more than a few hundred feet before they become densely covered with plants, and so are bound down. Moreover, in the constant swingings of river channels through their alluvial plains,—a movement which brings about a washing-over of all the deposits of these terraces in a brief geological time,—such dunes are apt to be destroyed before they attain any great size.

Sand Beaches.—We must now turn again to the development of sand beaches, and their relation to the physiography of any shore. The first point to be noted is that the beaches composed of sand are vastly more extensive than are those which are occupied by bowlders. On the Atlantic coast of the United States, which affords a fair gauge for a determination as to the proportion of shore lines in general, the sand beaches probably occupy at least ten times as much of the sea front as those which are composed of pebbles. In part this excess of sand on the shores is to be attributed to the fact that the rivers bring forth a certain amount of material; moreover, a considerable part of the fine-ground detritus which occupies the northern part of the continent owes its comminution to the action of the glaciers which recently covered that land. The share of the marine agents in these materials has been limited to their transportation and arrangement. It is, however, evident that there are other important conditions which have affected the history of sand grains, and exerted a very great influence in promoting their resistance to the influences which lead to their decay, and thereby led to the accumulation of arenaceous matter along the sea border. These conditions must now be considered.

It should in the first place be noted, that ordinary sand consists normally of quartz crystals which have been split along their cleavage planes to the point where the fragments are no longer easily broken; next, that this substance is, of all the common minerals of our rocks, the one which is least readily affected by the agents of decay; moreover, it has a relatively low specific gravity, and is also very hard, so that when tossed about by the waves it does not strike with violence, and so is much less subjected to wearing than most other rocks. In addition to these protective features, and much more important than they, is another and peculiar quality which sand acquires when it is completely wetted. In this state the grains lying with their faces against one another hold the water between them in a manner which makes it nearly impossible to force the neighboring surfaces together. This can be readily seen by applying pressure to wetted sand. Such force serves to squeeze out a portion of the water; but, even when applied at the rate of a thousand pounds to the square foot, there remains enough of the fluid between the grains of sand to keep them somewhat

apart, and thus to prevent the most effective friction of the faces upon one another.

To the action of capillary attraction, as above described, is due the fact, that, when the division of rock materials to the state of sand is brought about, all or nearly all the erosion due to the beating of the fragments together ceases. Some wearing is accomplished when the grains are caught between pebbles, and so come between upper and nether millstones. A certain though small and slow decay is brought about by chemical action; but in general the sand, while it is in the sea, is singularly well preserved from injury. We can the better note the measure of this preservation by observing what happens to the sand which comes into the possession of the wind. In this condition there is nothing to keep the grains apart. They wear rapidly, though they receive no such blows as are delivered on the beach by the surf. In the course of a few miles of journey the sand in the dunes is more worn than that which has moved for, it may be, a thousand miles along the shore. Thus the sand of northern Florida, which has traveled southward from the region beyond Cape Hatteras, is not more rounded than much which is in the inner or landward dunes of the coast within sound of the ocean waves.

The result of the protection against wearing which is afforded to sand grains by the water which surrounds them in the sea is of very great consequence in the history of the lands. As before remarked, by far the greater part of the marine shore lines are bordered by sands. Probably, the world about, over nine tenths of coasts are fringed by such beaches, composed of practically indestructible materials. Upon these bounds the ocean waves, which, when armed with pebbles, can successfully assail the hardest rock cliffs, break without effect. Were it not for these indestructible shields, the waves would long ago have reduced the land areas to much smaller proportion than they now exhibit.

Barrier Beaches.—The function of sand beaches in defending the land from the assault of the waves makes it interesting to note in more detail the ways in which these beaches are formed and maintained along the continental shores. The easiest way in which to approach this inquiry is by supposing that the coastal region of the southern part of the United States should be elevated in a geologically sudden manner, so as to

bring above the sea a part of the continental shelf which is still covered by the ocean waters.

The immediate effect of elevating a seaboard region which is fringed by the characteristic shallows of a continental shelf is to bring the surf line against an unprotected shore, so that it may attack it in a very effective way. So long as the waves are of ordinary height, they may break close in against the land, and their swash will proceed to carve out a cliff; the rocky waste thus formed being drawn back by the reflux of the waves, and serving to shallow the water for some distance from the shore. This process of shoaling will also be favored by the action of the waves, which, as they approach the land, will drag, by the friction which they exercise upon the bottom, large quantities of sand in toward the coast line. When the depth of the water has been thus considerably diminished, it will happen, in some great storm, when the waves have an unusual height, that they will break at a considerable distance from the land. The line of the surf may indeed be placed some miles away from the actual shore.

As soon as a line of breakers is formed, a number of conditions combine to bring about the formation of an elevation of the bottom at the point where the waves are overturned. Each wave in succession drags a certain amount of sand with it, this detritus being laid down when the wave overturns and is thus broken up. In some cases it may come about that the upward growth of this elevation takes place with such rapidity that in the course of a day or two, in which heavy seas prevail, the elevation may attain to near the surface of the water. If it happen to rise from the level of the sea, the permanence of the barrier is at once assured; if it fall short of that height, the lesser waves of the following ordinary weather are likely to overrun the elevation, and to scour away a part of its height. But in some subsequent great storm, the waves in which, on account of their height, have to break along the shallow line, the ridge is pretty sure to be built above the water level. When this height is attained, a portion of the sand brought in by the waves has a chance to become dry, and thus is easily moved by the wind. In this condition it is readily driven over the narrow ridge into the water of the lagoon which the barrier has formed, or it may accumulate in the form of dunes. As time goes on, the continued accessions of sand, drawn in from the sea bottom

by the waves, serve to widen the barrier, which in the course of a few thousand years may grow to the width of some miles.

"INLETS." — The barrier beach may, when originally formed, have great continuity. Occasionally, where there happen to be strong headlands with deeper water off their faces, the wall of the beach may come in contact with the land; but, as it is shown by many instances, the narrow island of the reef may extend in continuous manner for the distance of hundreds of miles along the shore. Owing, however, to the fact that the barrier acts as a dam to hinder the land waters from taking their natural course to the sea, it is sure to be breached by outlets from point to point along its length. Such breaches are usually miscalled "inlets."

It is characteristic of those breaches which give exit to the river waters, that they are formed and closed in a somewhat curious manner. It may generally be observed that the opening forms near the point where the barrier joins the headland, and that year by year the opening moves along the shore, the gap filling on the one side and cutting on the other, until it attains the next headland in its line of march. Then for a brief time, while the river waters bank up in the lagoon, the breach is closed, again to open at the point where, in the previous case, it was seen to begin. The reason for this singular marching of the inlets on a barrier beach is to be found in the fact that along these sand walls the detrital materials journey in one direction, which is determined by the set of the current which sweeps the shore. Thus along the Atlantic coast from Cape Hatteras southward, and also, though in a less determined manner, on the more northern parts of that shore, there is a southward-setting current, which makes a gradual drift of sand all the way down to Cape Florida. Hence it comes about that the sands fill in on the northern side of the inlet, and force the waters continually to widen the exits on their south banks, — a process which compels the passage to move down the coast. As each headland somewhat obstructs the southward march of the sands, the barrier beach is apt to remain lowest immediately south of where the ridge comes against the projecting part of the shore; and so, when the inlet has to form again, the breach is apt to occur at that point, — the place where it originally formed.

THE LAGOON or bay between the barrier beach and the mainland, being originally shallow, and receiving accessions of detrital matter from the rivers, from the sand blown over the beach, and

from the accumulations of organic remains, is gradually brought into the condition of a swamp, through which wander the streams which convey the land waters to the open ocean. When this state is attained, the detritus borne down by the rivers is again deposited beyond the coast line, where it serves to aid in the shallowing process, which is likely in time to lead to the formation of yet another barrier beach. Even without the intervention of river sediment, the other agents which accumulate sediments on the sea floors are likely to bring about a measure of shoaling, which results in the formation of these successive sand reefs, in the manner above described.

Although the foregoing account as to the formation of beach barriers along shores which have the characteristic continental shelf, shoaling near the coast line, has been prepared as a general statement, it may be taken as an account of the steps by which the elongate sand islands which inclose the lagoons and bays of the region south of Cape Hatteras and north of Cape Florida, as well as those along the northern shores of the Gulf of Mexico and elsewhere, have been formed. By consulting the excellent Coast Survey maps of the Atlantic shore of the United States, the student may note the fact that there is an almost continuous water way inclosed by these wave-made islands, extending in some cases for the distance of many hundred miles. Here and there the slightly higher parts of the land have formed capes with such a depth of water off their faces, that the barrier beach has been forced into contact with their shores; but so inconsiderable are these interruptions, that a small boat can, with infrequent portages, be navigated from near Norfolk, Va., to Bay Biscayne, in southern Florida. It has indeed been proposed to develop this natural water way into a ship canal, which would afford a safe and easy route for vessels passing along this dangerous portion of the continental shores.

Coral Beaches. — On certain portions of the ocean shores within the tropics, where a current of warm water, impelled by the trade winds, continuously moves in against the coast line, those species of polyp which dwell in communities, commonly known by the name of *corals*, are developed in a very plentiful way. These compound animals are common on the sea bottoms even in waters as far north as Cape Cod; but only where the species of the group are nourished by warm currents, such as often flow in upon the shores and shallows of the seas which are warmed by

a nearly vertical sun, do these creatures grow in such numbers and to such aggregate bulk, that they may form a coast line.

It is characteristic of coral beaches that nearly all the sand, or rather, we should say, the finely divided matter, of which they are formed, is composed of the skeletons or limestone framework which serves to support the coral animals while they are in the living state. This material is mingled with the débris of shells, and often in large measure with the limestone coverings of the small *Foraminifera*. While the corals are living, they are admirably adjusted to the assault of the waves in such a manner that the sea is practically unable to damage their communities. It is only when a colony dies in whole or in part that the waves are fairly able to make use of its fragments in building a beach. In fact, beaches of this nature depend for their growth and maintenance almost entirely on the work of extracting limy matter from the sea, which the coral animals accomplish in a second-hand way by consuming marine plants or other animals which have fed upon that source of supply.

The student who would obtain a clear notion of coral beaches should visit some shores of that description, such as may be found along the Keys of southern Florida or in the islands of the Bermudas. Selecting any portion of the strand which faces the open sea, he will observe that the beach is covered by a layer of whitish powdery rock, the grains of which are more rounded, and generally more variable in size, than are the bits of true sand of an ordinary shore. Carefully examining the material, he will perceive that, except that there is here and there a bit of pumice or volcanic lava blown so full of bubbles that it becomes light enough to float, all the débris of the shores is of organic origin. On the landward side of the beach he will commonly find a low cliff, cut either in the older part of the reef, which has been lifted up from the sea by the upward movement of the land, or in a dune-like accumulation composed of tiny bits of coral which have blown in from the strand when it dries in the hot sun. Whether this part of the reef which is exposed to the air is dune or elevated bottom, it is always easy to note the fact that the rock material is exposed to a rapid solution by the rain water. The result is that the dunes never attain any great height; moreover, they never march far inland, in the manner of sand dunes, for the reason that the limestone grains speedily become consolidated into a tolerably firm-set rock.

Looking to the seaward at low tide, the observer may note in the hollows of the surf the protruding tops of the living coral communities, which never attain a height above the plane of ordinary low tide, and which serve to maintain the large supply of matter which is continually being ground up by the action of the waves.

In most cases the coral shore lies upon a fringing reef, separated from the mainland by a shallow landlocked basin in which a host of frailer coral communities and other delicate marine creatures develop. These landlocked forms afford a great deal of limestone sediment in the form of mud, which is carried out to the front of the beach by the tidal currents. In some cases the amount of this organic débris is so large that it accumulates in the form of a considerable delta at the seaward end of the channels which connect the lagoons with the open water.

In the tropical oceans, and even in higher latitudes which are affected by warm currents, coral islands frequently abound which afford very interesting organic beaches. Islands of this nature are most abundant in the Pacific and Indian oceans, but they also occur in the Atlantic basin along the line of the eastern Antilles. They constitute the Bahamas, the greater part of the islands or Keys of Florida, and the beautiful archipelago known as the Bermudas. These oceanic coral islands commonly have an annular or ringlike shape, inclosing a basin or lagoon. Sometimes the ring is composed of a single island, through which there is but one breach connecting the inner and outer water. In other instances the ring is formed by many small isles, with shallow water ways between them. Coral deposits of this form, known as *atolls*, present very beautiful beaches of organic rock, that on the outer side being wide, and the seat of a heavy grinding action which the waves inflict on the dead coral; while the beach bordering the lagoon, of which the shallow waters are rarely more than a mile or two in diameter, forms a delicate strand of no great width, for the reason that the waves have not much power. From the outer beach the storm winds in dry weather sweep a good deal of powdered rock into rudely shaped dunes, which, being composed of fertile earth, often support a luxuriant vegetation of palms and other tropical plants. The combinations of beaches, and their products the wind-made hills, make the atoll the most singular geographical feature of the tropical seas.

It is characteristic of coral beaches that the materials of which they are composed, unlike those of ordinary shores, are readily taken into solution, and in that state may be borne away by the currents to any distance. As these reefs can only be found where ocean currents moving with considerable velocity come in contact with shallows or shores, the water which bathes them is always in motion, and so bears off the dissolved matter. Notwithstanding the constant robbery of their materials, which is effected by the solving process, the coral beaches often widen with great rapidity; the contributions of their débris which are made to the ocean floor are great in quantity as well as widely distributed; and the powdered waste which is blown to the landward by the winds is often sufficient to cover considerable extents of country.

A capital instance showing the constructing efficiency of reef-building corals may be seen in southern Florida, where the outer or southward third of the great promontory owes its construction to the development of successive fringes of coral growth on the beaches formed of the débris of these reefs, and of the detrital matter blown from the beaches into the shallows between them and the mainland.

Marine Marshes.—Closely related to the work which is effected by coral reefs is the organic result accomplished by other groups of living beings along all the shores of the world. We have already noted the fact that in the beach the results of marine action lead to the construction of a broad, gently sloping shelf, extending from the shore to a considerable depth of water. This slightly declining part of the sea floor affords an admirable site for the development of a great array of species both of animals and plants. Owing to the shallowness of the water, a share of the sunlight passes through the fluid to the bottom. The grinding action which takes place in the waves brings much mineral matter and organic material into the condition where it readily becomes fit to support the species which dwell in these shoals. The undertow and other currents transport this sustenance to the waiting throng of beings. In these and other ways the undersea portion of the beach becomes, of all the water-covered areas, the fittest seat of life.

Where, as is the case on most sandy shores, and also behind those coral reefs which fringe the mainlands, there are inclosed areas of shallow water, we find another realm extremely well

suited to organic development. As before noted in the case of coral-reef lagoons, these embayed waters are admirably suited to the growth of marine species. Among the animals, the bivalve *Mollusca*, particularly the oysters, find these sites very well suited to their needs. They often build deposits composed almost altogether of their shells, having a depth of many feet, and a horizontal extension of many square miles in area. In these embayed waters many species of crustaceans flourish, and at their death give their skeletons to the accumulation which gradually shallows the water. In this manner the areas fenced in by barrier beaches become floored with sediments, which, so far as their chemical composition is concerned, are admirably fitted for agricultural purposes. A large part of the fertile land of Holland has been won to tillage by completing the natural beach barriers which separate the fertile ground from the sea, the water from the fields being removed by pumps.

When the lagoons behind the sand beaches have become shallowed to the depth of ten or twenty feet, certain low-grade flowering plants, mostly of grasslike form, begin to convert the areas into *marine marshes*,—wide savannas which are covered by the sea for but an hour or two a day, during the time of high tide. The process by which the marsh growth takes place is very interesting.

A number of land plants have modified their original specific characteristics so that they are enabled to dwell in contact with or even under the sea, the salts of which are deadly to almost all vegetable species. Among these, the most interesting is that known as the *eel grass*, which, though a flowering plant, never lifts its form above the surface of the water. This species will take root in the embayed waters wherever the bottom is soft, and less than twelve feet in depth at low tide. Within the close-set stems dwell a host of marine creatures; moreover, the network entangles drifting sediments; the two actions—that arising from the death of organic life, and that from the floating débris which is caught, and brought to the bottom—serving rapidly to shoal the bottom of the lagoon. A number of other plants, mostly grasslike forms, begin to grow on the mud flats formed between the eel-grass banks and the shore. These species, which require to be above the water level for the most of the day, produce a very dense mat of vegetation by weaving their tough roots together, thus forming a mass which only heavy waves can break

up. In this manner the construction of the marine marsh is begun around the margins of the water field.

When the waters inclosed by a barrier beach have been brought into the state of a marine marsh, the area can, as experience shows, in most cases be readily won to the uses of agriculture. Wherever the rise and fall of the tide is eight feet or more, it is possible so to arrange dams, at the point where the sea water enters, that the level of the marsh may be kept permanently above the sea; then, by means of appropriate ditchings, and by removing the tough mat of grass and roots, rich and very enduring soils are made ready for tillage. Experiments made on the coasts of New England and elsewhere show that lands thus won from the sea are fitted to a great range of crops, and can be tilled for many years without requiring manuring.

Where the tides rise to a great height, as in the region about the Bay of Fundy, the strong currents created by the waters which enter and leave the embayment sweep with them great quantities of mud. In such regions the people have learned to construct artificial dams separating the mud flats from the sea, the barriers being provided with openings for the passage of the tidal waters. These waters, entering the artificial lagoons laden with sediment, are retained in the area until they have laid down their burden. When, by this process of deposition, the bottom of the inclosed space has been brought to near high-tide mark, the sea is barred out, and the new-made land is ditched and brought into the condition of profitable fields.

Although in this country the long-continued abundance of good land on the frontiers, which might be had almost for the asking, has kept people from paying much attention to the class of lands which have afforded the agricultural wealth of Holland, the time is soon coming when the marine marshes formed behind the barrier beaches along the Atlantic coast will be brought into condition to serve the uses of man. It seems likely that somewhere near twenty thousand square miles of extremely fertile soil will thus be gained to the service of our people when they have applied the methods of improvement which have been so successfully followed in the districts about the mouth of the Rhine.

Although the grasslike plants do the most of the work of winning the shallows from the sea in the manner above described, a

similar end is effected in the tropical parts of the world by the growth of the peculiar group of trees known as *mangroves.* All other forms of arboreal vegetation except the mangroves are unable to tolerate any considerable contact with sea water; but these trees, of which there are a number of species in different parts of the world, have varied their habits and their structure in a remarkable way, and have thus become competent to meet the peculiar conditions which they have to encounter in the lagoon behind the barrier reefs formed by the coral or sand beaches of warm regions. Beginning on the shore, the mangrove establishes its crown above the level of high tide. From this crown or junction point of stem and roots there extend off toward the sea long runner-like processes, which grow downward into the water until they attain the bottom, and there take root. From the upper part of these runners new stems arise; and the process may be continued until wide lagoons become covered with a low, dense forest, beneath which the tide may ebb and flow until the falling leaves and twigs, together with the remains of animals, have filled up the interspaces. In this way the mangroves win to the conditions of marsh great areas of embayed waters, and thus complete the work of barring out the sea which is begun in the formation of barrier beaches.

The foregoing paragraphs may serve to indicate in a general way something of the more important work in relation to organic life which is brought about through the growth of beaches and the work which is done upon them. This work consists in part in the formation of shallows next the shore, which afford a favorable site for the development of living forms; in the grinding-up of organic waste to a state in which it can readily be transported by the waters to the creatures which it is to feed; and in the development of extensive shallow landlocked basins, which by their conditions favor the growth of a great range of animals and plants. Having thus traced in outline the more important relations of beaches, we must now turn our attention to certain detailed features in these structures and their distribution.

Composition of Sand Beaches.—It should be noted, that, while sand beaches are extensively developed along the shores of all the continents, they rarely appear in anything but the most attenuated form on the smaller islands which exist at distances of more than a few miles from the shore, or which are surrounded by deep water. On such insular lands the ground-

up rock waste which goes to form sand beaches is likely to be swept away from the shores, the amount remaining being insufficient to afford characteristic beaches of this nature. On the seaward faces of the continent the long-continued shores afford an opportunity for the arenaceous material to journey for great distances, and to be accumulated on those portions of the coast toward which it is impelled by the prevailing direction of the wind and the current. Thus on the eastern coast of North America the sand derived from the wearing of the cliff or bluff shores which are wasting under the action of the sea (as those along the coast of New Jersey) journeys southward for a great distance. It is impelled in this direction because the average direction in which the waves run in from the sea is from the east, while the trend of the shore is southwesterly. The result is that the sands march down the shore, impelled by a current which is inflected to the south by the trend of the shore.

The reader can by a simple experiment illustrate the manner in which such a current is formed. Taking an ordinary basin of water, the breath from the lips can be used to form wavelets, which may be made to break against a straight-edged barrier. Using small floats, it can be noted that the resulting current sets down the barrier in the direction in which it inclines; that is, on the side of the obtuse angle between the axis of the air stream and the resulting waves and the opposing margin.

In its journeys down the long coast between Long Island, New York, and Florida, the moving sand, where it passes the mouth of a considerable river, is pretty sure to be thrust for a distance out to sea on the continental shelf. From this excursion to the seaward it is, however, returned by the action of the waves, and so comes again to the shore, or the very shallow water next it, and is thus free to go farther to the southward. As both the eastern and western shores of North America extend obliquely to the run of the waves, which come on the one side from the east and on the other side from the west, there is an evident tendency on both the Atlantic and Pacific coasts for the sands to work to the southward. This, however, is much more conspicuous on the eastern side of the continent.

We shall next consider some interesting details which may be here and there, though not continuously, observed along the beach lines wherever they are exhibited in their normal form. First among these we may note the materials found along the

strand which have not been derived from the wearing of the land or from the importation of pebbles or shells brought in by the scouring action of the waves from the neighboring shallows.

First among the list of casual contributions to the beaches we should perhaps reckon the débris from the arts of man. This consists not only of ordinary wrecks, which find their way to the beaches, but of a quantity of other materials derived from the arts. Noting first the wrecks, we observe that where a ship goes ashore on a bowldery beach, its framework, however strong, is likely in a few years to be beaten to pieces by the hard strokes which the stones deliver when set in motion by the waves. If it be a timber vessel, the fragments are ground to fine bits, and float away. If the craft be of iron or steel, the oxidizing action of the sea water, together with the wave work, insures a slower yet complete destruction. Rarely is any part of the wreck built into the submerged portion of the beach.

It is otherwise where a ship is wrecked upon a sandy strand. Because there are no stones to strike heavy blows in times of storm, the firmer parts of the vessel may endure in a little-worn state for many years. In some cases, hewn timbers exposed to the stroke of a powerful surf will keep their squared shape for a decade or more. If they are below the level of high tide, they are apt to receive some protection from the barnacles, shellfish, and other organic forms which find a lodgment upon them. Moreover, the whirling currents formed when the waves break against the hulk are likely to excavate the sand beneath the bottom, and thus allow the remains of the craft gradually to settle down into the loose material; so that in the course of a few years the framework of a considerable ship may disappear from view. If the beach goes on widening (a process which is apt to take place), the vessel may in time come to lie quite a distance inward from the margin of the water; there it may lie hidden, unless some whirling action of the wind, such as makes and unmakes dunes, strips the covering away. A section across any one of the wide beaches of Europe, which has been receiving wrecks for two thousand years or more, might well disclose a succession of castaway vessels dating from the beginning of the seafaring art to the present day, lying one beyond another to the seaward in the order of their antiquity.

Along almost all shores of the open sea, the débris of other human arts exceeds in quantity that which comes from wrecks

occurring on the shore. The range and variety of this débris which bears the impress of the hand of man are exceedingly great. On almost every sandy beach in New England the trained observer can find in a few minutes' walk fragments of shaped wood which have evidently drifted from the tropics, borne northwardly by the Gulf Stream, and driven away from its surface by the winds which blow shoreward over that current. Along the coast of Florida it is common to find logs of mahogany hewn into shape on the banks of rivers in South America and Central America. So considerable is the amount of wood carried northward by the Gulf Stream, that the people of far-off Iceland obtain their supplies of such material from the drift which comes upon their shores. Thus imbedded in an extending sand beach we may find the more solid parts of trees which have journeyed from the Equator to the Arctic Circle.

Yet another curious element in the composition of the sand beaches is the volcanic pumice, which plentifully finds its way in ocean currents from one sea to another, and which naturally drifts to the shores. In almost all volcanic eruptions of a high order of intensity, the quantity of this lava, so filled with gas and steam vesicles that it will float, is very large.

When pumice comes to the sea, it is capable of floating for a very long time. Unless it becomes weighted down by the growth of animals and plants, the bits are apt to find their way to the shores. Inspection of the sand beaches along the Atlantic coast of the United States shows that this pumiceous matter is an important element in the composition of these strands. It seems likely that any cubic yard of the sand from the shores which face the open sea will reveal recognizable fragments of this nature, though the greater part of the bits will be of small size.

Coming upon pebbly beaches, fragments of pumice, because of their frail nature, are quickly ground to unrecognizable powder. On sandy shores, although the material is broken up by the action of the waves, the process of comminution goes on more slowly. As might be expected, the amount of pumice which comes to the shores varies greatly on different parts of the coast. Thus along the shore of Florida, from Bay Biscayne northward to Jupiter Inlet, the writer has found fragments of pumice more plentiful than on any other portion of our shores.

Peculiar Features in Beach Structure.—Having gained a general idea of beach structure, the student should now notice

certain peculiar features which may be observed on the surface or in the interior of these accumulations.

The most interesting marks which may be noted on the shore are those which are formed by the movements of the water as it is impelled by the waves. These are of a very varied nature. Selecting any pebbly beach where the stones are prevailingly of small enough size to be readily tossed about by the waves, the observer will note that at almost all times, but especially after a heavy storm, the slope from the high-water line downward is scalloped in a curious manner. From the level beyond the waves, ridges tapering outwardly extend down the incline, it may be, for a distance of from ten to fifteen feet or more, and a height of from a few inches to two or three feet. Between these ridges, which taper toward their lower and outer parts, there are small wedge-shaped embayments, which at the outer edge of the ridges may be from two or three feet to fifteen or twenty feet wide, tapering thence, like the section of a rather pointed cone which is obtuse at the apex, to the edge of high water. These scallops may, under favorable conditions, be traced in orderly and uniform succession along miles of shore.

It seems to the writer that these scallops are formed about as follows: In a time of storm the inner edge of the swash line formed by the body of water which sweeps up and down the beach has a very indented front, due to the fact that it is shaped by a criss-cross action of many different waves. As these tongues run up the beach and strike the pebbles, they push them back so as to make a slight indentation where each tongue strikes. As the water goes back, it pulls out the fine material, but does not withdraw the pebbles. The next stroke of the splashing water then finds a small bay, the converging horns of which slightly heap up the fluid, making the stroke a little harder in the center of the tongue, and excavating the bottom of the bay still further. As the reëntrant grows larger, and the tide rises higher, the water, as it runs up, forms a small wave, which breaks on the shore of the recess, and casts the pebbles more into the form of a ridge. This action, continuing for some hours before the tide turns, serves to shape the embayment.

It should be carefully noted that, when the swaying waters rush up into the shore scallops, the converging walls of these indentations deepen the current, and add to the efficiency of its movements,—a process which is essentially like that which is

brought about when an ordinary wave enters into a recess of the cliff, or the tidal undulation is crowded into an indentation such as the Bay of Fundy.

Reference has been made to the fact that the water from the land emerges through the upper part of the beach. If the quantity is large, it may happen that the outflow is sufficient to keep the grains of the débris some distance from one another. In this case quicksands are formed, which may be inconvenient or even dangerous to the unwary explorer. Quicksands are of relatively rare occurrence along the seashores: they are more abundant on the beaches of rivers, where the conditions favor the escape of springs upward through the accumulations of sand.

Here and there, where waters from the lagoons behind the beaches have made fresh-cut channels, the observer may note the peculiar form exhibited by the beds or layers of which the beach is composed. He will see that in place of the orderly succession of beds which he may have noticed in ordinary stratified rocks, which in almost all cases have been formed on sea bottoms away from the shores, the beach strata are considerably inclined, and that each layer or group of layers is apt to be intersected by other layers lying at different angles. This tangled structure is recognized by geologists as a characteristic mark of beach accumulation. It somewhat resembles the layers formed in dunes and those built in deltas. It will be worth while for the student to work out these differences, if, as is often the case, the sand beaches which he is studying afford opportunity for such inquiries.

Elevated or Depressed Beaches.—We have now completed the outline description of the conditions which determine the formation of beaches. There remain, however, many minor points of much interest, which should be set forth in order to complete the account of these interesting features. First of these we may note the *elevated* or *depressed* beaches formed along shore lines, which have, since their period of activity, been lifted above or lowered beneath the surface of the waters.

Along nearly all the coast lines which have been attentively examined by the students of coast phenomena, it has been observed, that, at various heights above the present sea level, there are more or less evident remains of ancient sea beaches. Thus, scarcely any portion of the Atlantic coast of the United States has failed to yield evidence of this nature. Generally

speaking, marks of this contact of the sea and land during former adjustments of level are most conspicuous at heights of less than one hundred feet above the present shore; but in many cases they may be indistinctly observed at several times that elevation. It will be readily understood that the higher a beach is in general, the longer the time during which it has been subject to the agents of destruction—the rain, the frost and wind, as well as the cutting of the streams—which tend to destroy its original form. It is therefore rarely the case that we can definitely trace the position of shore lines which were formed during the earlier geological ages and afterward elevated into the air. In fact, all the important raised beaches which are well known are of geological age and date.

Although the course of the land movements is generally upward, it not infrequently happens that the downward settling or tilting of the land carries the sea margin below its original position. Such accidents can rarely be traced, except by indirect evidence. The slope of the beach, or even the characteristic ridge of a sand barrier, is likely to be obliterated by the dragging action of the waves. It is sure to be leveled over by deposits of detritus, so that its form cannot be traced by the sounding lead. It is only where steep sea cliffs have been lowered beneath the water that we can expect to find any evidence by soundings that a recently formed shore line has been depressed beneath the surface of the ocean. All along the Atlantic coast, from Newfoundland to Florida, there are abundant evidences afforded by submerged forests, which go to show that the shore line has recently been much farther out to sea than it is at present. Other proofs of the same general nature are afforded by the extent to which river valleys excavated by stream action have been invaded by marine waters. These considerations, though more evident to the trained geologist than to the beginner in the science, may be taken to prove a subsidence of the Atlantic coast line, or at least a relative gain in the height of the sea waters, which has brought the shore inland from a former station for a distance of some miles.

In considering the uprising and downsinking of beaches, it need not be supposed that great differences in the movement of large areas of the earth's surface are involved in these diverse results. It seems likely, indeed we may say almost certain, that the interior parts of the continents are generally

moving upward, while the sea floors are generally moving downward, in those great wrinkling processes of the earth's crust which developed the arches of the land and the basins of the sea. In this movement, which the reader may for convenience represent to himself by holding a pencil in the middle of its length and in a sloping position, it is evident that we may regard the section from the interior of the land out to the bottom of the sea as a bar or lever, which has a fulcrum point represented, in the case of the pencil, by the point at which it is held between the fingers. Now, if it happens, as it probably does in most cases, that the fulcrum point is near the shore, we easily perceive that the land may rise and the sea floor sink without necessarily depressing or elevating the beach. If, on the other hand, the fulcrum point is to the landward of the shore, the motion will carry the beach below the plane of the sea; while, if the rotating point be under the sea, the beach will be gradually elevated. In this way we may account for the very numerous changes in the position of beaches without having to suppose that the land changes the general nature of its movement.

Effect of Beaches in the Formation of Harbors.—This is a matter at once of scientific interest and of economic importance. There are two ways in which the growth of a sand beach may lead to the formation of shelters for ships. Where a sand-barrier reef forms offshore, it often happens that one end of the strip does not lie against any promontory, but ends in the open water. Instances of this sort may be noted at many points along the Atlantic coast of the United States. Although the sea behind such spits of sand is commonly not very deep, the shelter which they afford is often of much value to the smaller vessels, such as are engaged in the coasting trade. Where such a sand beach is extended by the action of marine currents, especially where it projects into a bay, its extremity is apt to be turned in its growth by the action of other currents until it assumes the form of a hook, such as may be noted near Provincetown, Mass.; at Cape Pogue on Martha's Vineyard; and at many other points along the shores to the southward. Another group of sand-bar harborages owes its origin to the inlets or breaches which are formed where the waters of a lagoon, overfilled by the rivers, break out into the sea. Good instances of this nature abound along the Atlantic coast south of Cape Hatteras. These passages

from the open ocean to the sheltered expanses of the lagoons or bays are generally shallow. In almost all cases they are much obstructed by extensive sand bars both on the outside and inside of the opening, — shallows formed by the tidal currents, which obtain considerable energy as they move in and out of the narrow channel. As a class, sand-bar harbors are, because of their shallow nature, of less value than are those which are formed in other ways; but in many regions, as along the southern coast of the United States, they are about the only shelters for ships.

SUMMARY. — We have now considered the most important phenomena of beaches, and the share which these structures have in preserving the land from the assaults of the sea. It would be possible to extend indefinitely an account of the facts of the physical nature which these structures exhibit. Such details, however, would best be left to the unaided inquiry of the student who undertakes the study of particular parts of the shore. Such a person will do well to extend his inquiries along two lines,—the one leading to an investigation concerning the effect of winds from different directions in altering the details of sand beaches; and the other, to the development of the various species of animals and plants along both the rocky and the sandy shores. Inquiries of the kind above advised may, if properly directed, prove of great service not only to the original observer, but to the science which he is pursuing. Well known as are the coast lines in a superficial way, no portion of them has yet been so studied as to complete our knowledge concerning the features which they exhibit. .

It will be well for the reader to understand that the foregoing account of beach phenomena deals only with the simpler results of the complicated forces which take effect along the lines where the waters come in contact with the land. Many of the more important problems which are presented in this most interesting field of inquiry are not touched upon in this brief essay. Some of them, indeed (as, for instance, the details of wave action), have necessarily been avoided, for the reason that their adequate discussion demands a treatment by means of the higher mathematics. It may, however, be hoped that enough has been set forth, though in mere outline, to guide the student on the way to investigations which he may independently pursue.

THE NORTHERN APPALACHIANS.

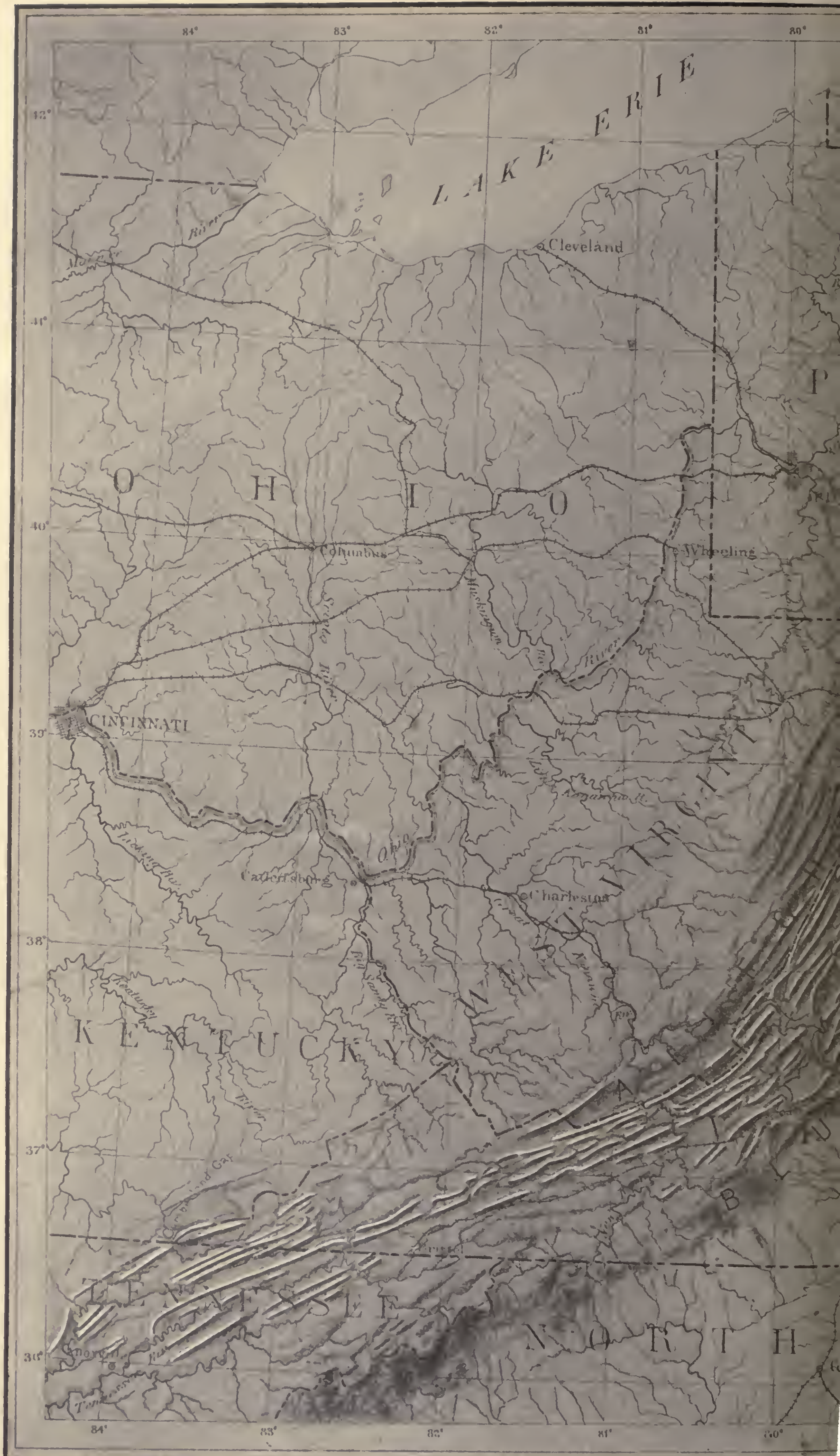
By Bailey Willis.

ENUMERATION OF TOPOGRAPHIC FEATURES.

Usually a mountain range is marked by a central crest, but the Appalachian ranges are characterized by a central zone, the surface of which is lower than the ranges on either side. This zone is a very complex valley, or series of valleys, and is known by different names in different sections of its length of a thousand miles. In its entirety it will here be designated the "Greater Appalachian Valley," or the "Greater Valley," and its parts will be referred to by their local names. In eastern New York the Greater Valley lies between the Catskills and the Green Mountains of Vermont, and its southward extension is the Wallkill Valley and the Paulinskill in New Jersey. In Pennsylvania it includes the Lebanon, Lancaster, and Cumberland valleys; in Maryland, the Hagerstown Valley; in Virginia, the Shenandoah; and throughout Pennsylvania, Maryland, and Virginia, the western portion is occupied by the Alleghany ridges. Still farther south it is the valley of East Tennessee, which, dividing at Lookout Mountain, extends into Alabama and Georgia.

Two principal ranges bound the Greater Appalachian Valley,—one on the southeast, the other on the northwest; the former being generally known as the Blue Ridge, the latter as the Alleghany Front. They extend in two nearly parallel lines about 75 miles apart.

The Blue Ridge is a mountain range of prevailingly gentle slopes, rising to rounded spurs and knobs. It is everywhere soil-covered, and clothed in forests or cultivated fields. It is nowhere naked or barren. In those sections where wealth creates summer homes, driveways of easy grade swing around the broad mountain shoulders, which are dotted with villas and spread with green lawns. Even in the more remote districts,



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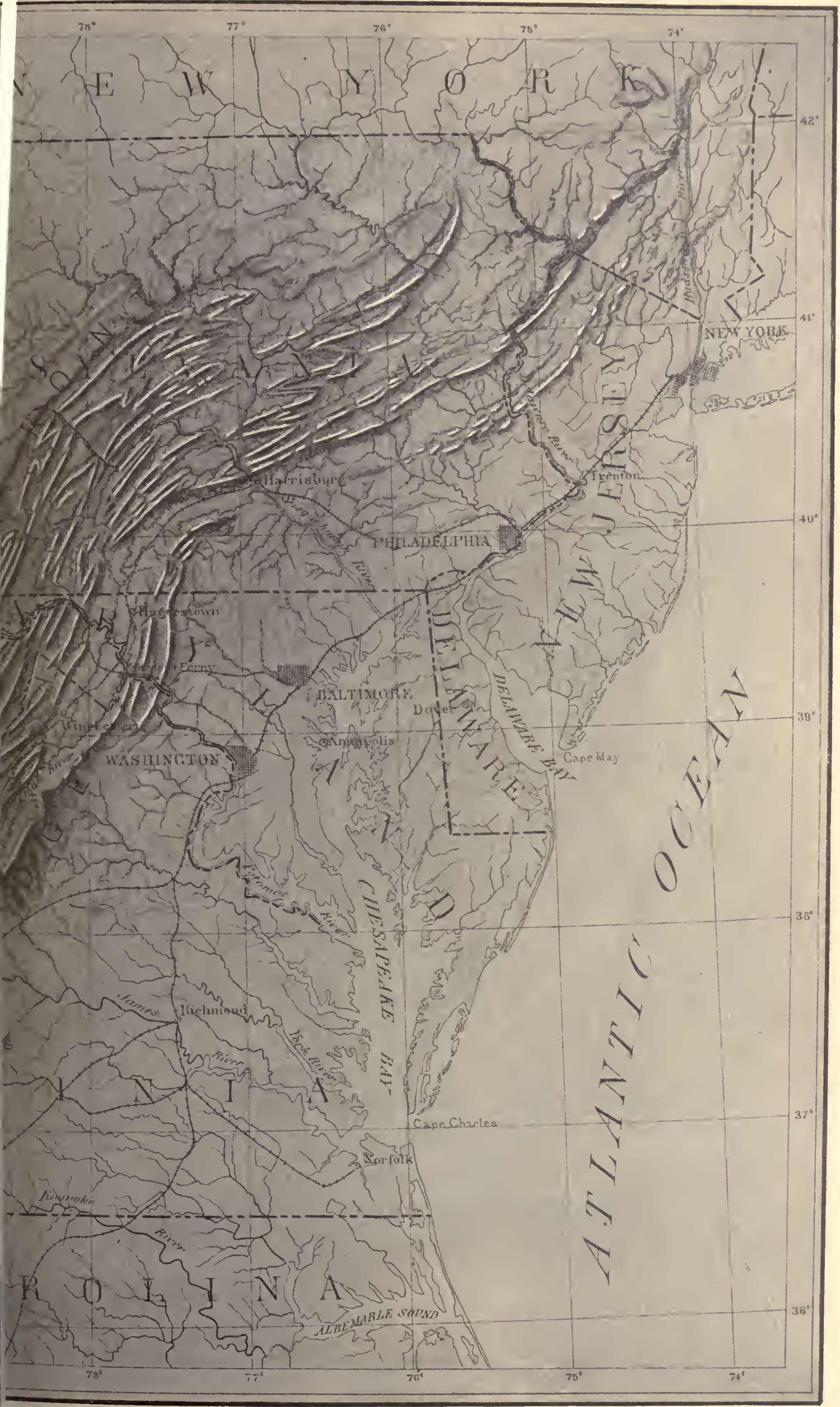


NEW YORK
NEW YORK
NEW JERSEY
DELAWARE
ATLANTIC OCEAN
Harrisburg
PHILADELPHIA
Trenton
Hagerstown
Ferry
BALTIMORE
Dover
Annapolis
WASHINGTON
Winchester
DELAWARE BAY
Cape May
CHESAPEAKE BAY
Potomac River
James River
Richmond
York River
Cape Charles
Norfolk
Roanoke River
ALBEMARLE SOUND
Hudson River
Delaware River
Susquehanna River
78°
77°
76°
75°
74°
42°
41°
40°
39°
38°
37°
36°

cabins and cornfields nestle among the mountain's arms, and cattle find pasturage on the summits. In New Jersey the Blue Ridge is represented by the highlands above Morristown; in Pennsylvania it is called South Mountain, and reaches an elevation of 2,000 feet above the sea, or 1,000 to 1,500 feet above the adjacent Cumberland Valley. Between the Susquehanna and Potomac the range lessens in bulk and height to narrow ridges but 1,300 feet above the sea. The Potomac, whose channel at Harpers Ferry is at an elevation of 300 feet, is overlooked by the historic eminences of Maryland and Loudon heights, which are but 800 feet higher than the river. Southward through Virginia, however, the ridge becomes broader and higher: 30 miles from the Potomac the altitude is 2,000 feet; 17 miles farther is Mount Marshall, 3,150 feet; 11 miles beyond is Marys Rock, 3,000 feet; and Stony Man and Hawks Bill, 4 miles and 7 miles respectively from Marys Rock, and opposite Luray, are 4,031 and 4,066 feet above the sea. These are the highest summits of the Blue Ridge north of North Carolina, and it is 10 to 16 miles across at this point. In the section between the Potomac and Mount Marshall there are three deep gaps,—Snickers, Ashby, and Manassas gaps,—cut down to levels of about 1,000 feet. Manassas Gap, farthest from the Potomac, is about 50 feet deeper than the other two; and waters of the Potomac, the Rappahannock, and the Shenandoah rise in a small plain east of the gap. In the section south of Mount Marshall and extending 100 miles to the James there are numerous gaps at an altitude of about 2,300 feet.

The western wall of the Appalachian trough, the Alleghany Front, is characterized in its typical development by a bold southeastward-facing escarpment and a gentle northwestward slope. It is the edge of the Alleghany Plateau. Its northern end touches the Hudson River, and is called the Catskill Mountains. Thence it stretches southwestward with a general elevation of 2,000 feet; but in northeastern Pennsylvania the Front is lost among the ridges which form the rim of the anthracite coal basins. The plateau is characteristically developed, however, west of Wyoming and Nittany valleys, and the Alleghany Front is equally well marked. In this section it is climbed by the Pennsylvania Railroad in the Horseshoe Bend between Altoona (1,180 feet) and Cresson (2,020 feet). The Front crosses Maryland between Cumberland and Frostburg; Dans Mountain,

2,100 feet above the sea, being a conspicuous point. South of the Potomac, it rises in the Pinnacle to 3,007 feet, in Pigeon Roost to 3,400 feet, and in Roaring Plains to 4,400 feet. Little High Knob, 26 miles from the Potomac, is a corner, 4,200 feet above the level of the sea, in the boundary between Virginia and West Virginia. Thence southwestward the Alleghany Front declines in elevation, and becomes less sharply marked. The Chesapeake and Ohio Railroad pierces it in a tunnel 2,100 feet above the sea in passing from the head waters of the James River to the valley of the Greenbrier River. New River, flowing northwestward, enters the plateau in a canyon 1,500 feet deep, the general elevation of the crest being more than 3,000 feet. In the Big Black Mountains of Virginia and Kentucky the Front again attains heights of 4,000 feet; but the summit is lower in Tennessee, and at Cumberland Gap it is but 1,600 feet.

Many streams cross the Alleghany Front. Rising in the plateau, they all, with the one conspicuous exception of New River, flow southeastward, and emerge from deep canyons into minor valleys of the Great Valley. It will be seen later that in its apparently peculiar northwest course New River pursues the more natural direction of flow, and that the Delaware, Susquehanna, Potomac, James, and Roanoke rivers reverse the courses they might, in the light of the ancient history of the province, be expected to take.

As compared with the Blue Ridge, the scenery of the Alleghany Front is rugged, yes, savage. The eastern face is steep, lofty, and often crowned with a precipice of sandstone. The canyons, a thousand feet deep or more from the plateau to the rivers, are narrow, and the profiles of the opposing walls are as bold as the eastern escarpment.

Between the opposite ranges of the Blue Ridge and Alleghany Front stretches the Greater Appalachian Valley. Its surface has a general slope, which is interrupted by depressions and heights. The depressions are channels cut by the streams in intaglio (that is, sunk below the general surface) 10 feet to 200 feet deep. The heights are long, narrow ridges, which remain in bas-relief (that is, stand out above the general surface) upon the plain, rising 600 to 800 feet above it. They are ranged in lines, frequently parallel among themselves and to the Blue Ridge or Alleghany Front. Through Pennsylvania they sweep in a majestic curve, which is followed by all the ridges from

Kittatinny Mountain to the Alleghany Front, and which bends down into Virginia as far as New River.

A strip along the southeastern side of the Greater Valley is distinguished from the northwestern portion by the general absence of ridges above the prevailing plain. The ridgeless strip is known as the Appalachian Valley, the Great Valley, and locally simply as the Valley. Its surface rises from a least elevation of 500 feet above the sea, in Pennsylvania, to its greatest altitude, 1,700 feet, in southern Virginia. Thence southward it gradually declines.

Northwest of the Valley, dividing the Greater Appalachian Valley, runs a ridge called Kittatinny (or Blue) Mountain, north of the Susquehanna and between the Susquehanna and James rivers more commonly called North Mountain. In Virginia part of the range is named Little North Mountain, and a higher one immediately northwest is North Mountain. Although divided by many gaps as deep as the Valley level, and varying in height from 200 to 1,500 feet, this ridge is a practically continuous feature throughout a distance of 400 miles. Its crest is often a rocky ledge less than 50 feet across, yet it maintains a uniform elevation over long stretches.

Northwest from Kittatinny Mountain the Greater Valley is divided by the many parallel Alleghany ridges which succeed one another to the Front as wave lies beyond wave on the sea. They are generally narrow-crested, steep, and long. Hidden among them is Kishicoquillis Valley, a fertile plain 25 miles long and from 1 to 5 miles wide, completely encircled by mountain walls. Beyond them, in the sunset shadow of the Alleghany Front, are Wyoming and Nittany valleys. The former is slightly crescent-shaped, 55 miles long and 6 miles wide, and is smoothly floored by deep alluvial soil. It is the Northern Anthracite Basin. Nittany Valley presents a less even plain, the surface being deeply channeled by many streams; but the fertile, rolling valley is charmingly diversified in its aspects, and contrasts beautifully with the escarpment of the Alleghany Plateau. Its length is 60 miles, but the southern arm, Morrisons and Friends coves, extends the feature 50 miles farther. The width varies from 2 to 10 miles, and there are several divergent coves.

In Virginia the Alleghany ridges are of a broader, less linear type. They are frequently oval, in horizontal and vertical sec-

tion, both with comparatively smooth and gentle slopes. The valleys between the ranges contain still broader but lower ridges, among which the head waters of the Potomac and James rivers flow in deep, narrow gorges. The soils are thin, and the district is less closely settled than the corresponding section of Pennsylvania.

Throughout Pennsylvania the Alleghany ridges are from 1,500 to 1,800 feet above the sea, but, like the level of the Valley, the Blue Ridge, and the Alleghany Front, they rise toward the south. In Virginia many of the ridges exceed 3,000 feet in altitude; and Elliots Knob, 20 miles west of Staunton, has an elevation of 4,473 feet.

Ordinarily a great valley is the home of a great river, which flows the length of the valley, gathering the waters from the environing mountains. The Mississippi is an example; and in the Southern Appalachian ranges the Holston and Tennessee rivers above Chattanooga illustrate this relation of an extensive valley which holds a single river system. But in the Northern Appalachian ranges there are several river systems, and their main streams traverse the ranges in channels which are in a measure independent of the ridges. The Delaware, the Susquehanna, the Potomac, the James, and the Roanoke, all cross the heights. New River also cuts across, though in the opposite direction. Even the tributaries are not confined by the ridges. Following down some stream, we see the valley extending indefinitely, an easy path for the loitering waters. The mountains rise on either hand. Suddenly the river turns off at right angles, and, dashing through a narrow gap in the forbidding ridge on one side or the other, emerges into another valley parallel to its former course. We shall see that the transverse rivers are older than the existing ranges, and that they developed their courses on a broad plain.

The rivers of the Northern Appalachians flow either to the Atlantic or to the Ohio River. The divide between these groups of streams is winding and often inconspicuous, having no definite relation to the principal heights. The Delaware, Susquehanna, and Potomac rise west of the Alleghany Front, which they cross, and, continuing eastward, traverse the Alleghany ridges and the Blue Ridge to reach the Atlantic. From among the Alleghany ridges of Virginia, the James and Roanoke flow through the Blue Ridge eastward. New River, on the contrary,

has its source east of the Blue Ridge in North Carolina, and runs northwest across the Blue Ridge, the Alleghany ridges, and the Alleghany Front, to the Ohio. Thus the main divide passes diagonally across the Appalachian ranges from a position northwest of the Alleghany Front in Pennsylvania to one east of the Blue Ridge in North Carolina. Within the Greater Valley, between the Blue Ridge and the Alleghany Front, the divides between minor streams are intricate; but, again, they are peculiar in being distinct from the valley ridges which they serve to connect, but do not follow.

DESCRIPTION OF THE TOPOGRAPHIC FEATURES.

The marked characteristic of views in the Appalachian ranges is the level line in which the even ridge tops appear in silhouette against the sky. In landscapes, as in architecture, sky lines are typical. The severe outline of a Greek temple is a form distinct from the graceful spires of a Gothic cathedral. Not less widely do the even profiles of the Appalachians differ from the serrate sky lines of the Rocky Mountains.

From the deeply cut channel of a stream in the broader stretches of the Appalachian Valley we may ascend to a hilltop of the general level. We climb a slope of soil, wooded or cultivated, and advance upon the level summit of the knoll. It is not a commanding height, and yet in the absence of woods we may survey a broad landscape. There are many even-topped, rounded hills: they join one another, forming a gently rolling surface, in which the streams are more or less deeply sunk in intaglio. Were the trench-like valleys filled to the uniform elevation of the hilltops, the surface would be a plain.

Looking northwest or southeast, we see, limiting this carved surface, a ridge which reaches far to the right and left. Its crest meets the sky in an even line, which is broken here and there by gaps. Some gaps are slight V's, which scarcely interrupt the otherwise even line. Other gaps are cut down to water level, and are occupied by streams passing through the ridge.

This view is across the trend of the ridges, across the grain of the country. Turning to look in the direction of the trend, northeast or southwest, we may see rising from the plain a row of knobs, one behind another, each farther one higher, to one which reaches the altitude of the level ridge tops. It is the end of a ridge which extends away for many miles.

Thus the relief of the Appalachian landscape has three classes of features: namely, the river channels with their associated level bottoms; the upland or general level of the valley, which is more or less cut into rounded hills of nearly equal elevation; and the ridges, which also in a general way rise to a uniform altitude. Let us consider these features more in detail.

It is the habit of rivers to do one of two things: they either dash swiftly down a rocky course, actively cutting the channel and carrying whatever sediment they receive; or they linger between alluvial banks, here and there rippling over a gravel bar. Thus loitering, they drop their burden of sand and mud, leaving it till a freshet gives them energy to lift and sweep it farther. Appalachian streams leap and loiter alternately. Usually the quiet reaches extend where the waters wind about in the valleys trending northeast or southwest, and the cascades are found where they traverse a ridge descending to a parallel valley. But when a small stream joins one much larger, there is often a rapid or waterfall in the smaller of the two near its mouth.

Occasionally in the large rivers a swift current running in and out among rocky islets is margined by alluvial plains. Near Harrisburg, the Susquehanna, which is there broad and shallow, shows this association of a stream at work upon rock bottom, between banks of gravel and sand which it formerly deposited. The difference between the banks and the channel shows that the condition of the river has changed.

With a given current and volume, a river can transport a certain amount of gravel, sand, and mud. If it receives no more than it can carry, it cuts its bed; but if it is overloaded, it deposits some of the sediment. In that case, if at some subsequent time the river should gain in volume or velocity, or receive less load from above, it would go to work to remove the beds of gravel or sand it had left behind.

The Susquehanna near Harrisburg was formerly overloaded, and spread alluvial formations broadly. Either because it flows more swiftly or is less loaded from its upper courses, it has now removed the sediments down to the rock. Other rivers also show this character.

The depth of the sunken channels cut by the streams in the general valley level varies with the size of the streams from 50 to 600 feet. The great rivers have cut deepest, the smaller

streams less deeply, the brooks least; but all streams flow most of their courses in narrow gorges with limited bottom lands.

These channels are so intimately related to the streams, that there can be no doubt of the truth of one of two propositions: either the streams took up their present courses because they found them to be the lines of least altitude, or the streams flowing in these courses have cut out these lowest lines. In the gulley by the roadside or on the hillside, in a heavy rain, you may catch the rivulets at work. The shower over, you may study the forms they have carved. Down the gulley, down the brook, the creek, and the tributary to the great river, you can trace the features of the same class, though of constantly increasing magnitude, and, noting the burden of mud which the waters bear, you may realize that rivers do not find their valleys: they make them.

The general level, with which the depth of the river channels has been compared, is not a uniform feature of the great valley between the Blue Ridge and the Alleghany Front. There are two classes of districts in which it is wanting. Near the larger streams it is usually worn away, or so divided into many low hills that it cannot be recognized. On the other hand, among the higher ridges, where they are closely ranged, the broad plain was not developed.

The plain is well preserved in the Lebanon, Lancaster, and Cumberland valleys of eastern Pennsylvania, and in their southern continuation, the Shenandoah of Virginia. It is also to be seen high above the present levels of the streams in the Nittany Valley of central Pennsylvania, and in Kishicoqnillis, which lies in the heart of the ranges. These valleys are all of limestone, with some areas of shale (or limy mud rock) in the larger ones.

But the plain is not clearly evident in northern Pennsylvania in the anthracite basins, nor in the central part of the State along the Juniata, nor in West Virginia on the head waters of the Potomac and James rivers. In these districts, where hills rise above the rivers, yet do not attain the altitude of the high ridges, they are nevertheless of such height, and so bold in their outlines, that they do not immediately suggest the ancient plain out of which they have been carved.

The high ridges next demand description. We have seen that in the side view these ridges present a horizontal crest interrupted by gaps. With a nearly uniform elevation they ex-

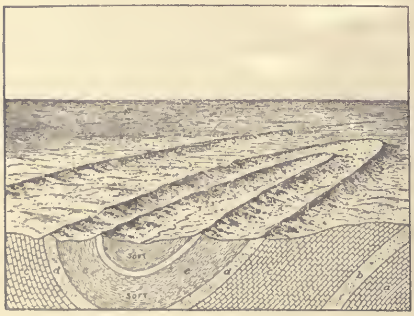
tend for many miles, but at intervals of from one to five miles they are notched to a depth of a hundred feet or more below the crest; and at longer intervals the notch is cut down to the base of the ridge, and is occupied by a stream. In the end view the section across one of these ridges resembles a right-angled triangle laid on its longest edge,—on the hypotenuse. The apex of the right angle, then, represents the crest of the ridge; and the sides of the right angle are the slopes of the ridge. The cross section may, however, have various forms. One slope may be much steeper than the other. The steeper, being perhaps precipitous near the summit, departs from the straight lines of the triangle and descends in a curve, gradually becoming less steep; the gentler slope, approaching the horizontal, extends uniformly to some distance. This forms the unsymmetrical ridge, of which the Alleghany Front, with its bold eastern face and gentle westward slope, is the extreme type. In other cases the two opposed slopes are more nearly equal, and the cross section of the ridge may approach symmetry or be quite symmetrical. In the symmetrical ridge both slopes are steep, being nearly forty-five degrees near the summit.

These sharp-crested ridges, called *monoclinal ridges*, run in long lines, straight or curving, often for many scores of miles. They may simply die out, but frequently they pursue a sharply zigzag course. Then the ridge rises to a culminating point, higher than the extended crest; and from this point another ridge, which is really but a continuation of the first, returns at an acute angle with the former's course. The ridge and its opposite section, or continuation, are related in position as are the sides of a canoe, and the high peak occupies the position of the elevated prow. After a course of a few miles, the second section turns again, but less sharply and without a higher peak, into a third section, which extends parallel with the first section. At the end of the third section, where it passes into a fourth, there is again a higher peak,—a canoe prow,—and the angle of the zigzag is sharp. Valleys which lie between the first and second sections, or between the third and fourth, leading up to and ending in the prow of the canoe, are called *canoe valleys*. The intermediate valleys, lying in the position between the second and third sections, have no familiar name; but they are *anticlinal valleys*, presently to be explained, while the canoe valleys are more accurately described by the term *synclinal valleys*.

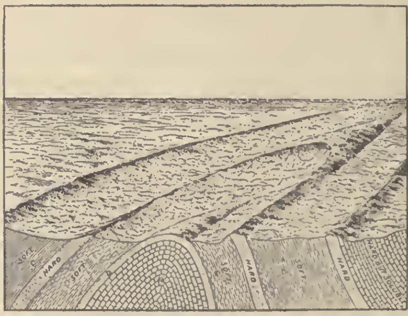
Occasionally the canoe valley is simple, and closed at both ends, while the drainage escapes through one or more gaps in the side. Sometimes such a canoe occurs as a long, narrow, and shallow hollow in the crest of a mountain many hundred feet above the general valley level. The feature is then called a *synclinal mountain.*

The Wyoming Valley is an example, on a large scale, of a simple canoe valley. The anthracite basins are complex canoe valleys, and the zigzag ridges by which they are shut in are beautiful examples of their kind (p. 183).

These forms are the prevailing ones in Pennsylvania and Virginia. In both these States and in West Virginia there is also another type of ridge, which is oval in cross section and in longitudinal section. An example of this type may be found in Great North Mountain, which rises from the Valley northwest of Winchester, and extends 30 miles southwestward, declining to the North Fork of the Shenandoah River. Rock Enon and Capon Springs lie on its northwestern flank. This mountain reaches an altitude of 2,700 feet in its northern section, 1,700 feet above the general level of the Valley. In the same locality it is 3 miles wide at the base, and bears a broad, rounded summit. When seen in a view in which it presents its northern end, it resembles an arch. When viewed in a northwesterly direction, its



Synclinal Fold, with Central Canoe-shaped Valley.



Anticlinal Fold, with Hemi-cigar-shaped Mountain.

profile is hemi-cigar shape. The mountain is indeed an arch of sandstone, an anticline which has to some extent been denuded of the strata that formerly covered it.

In the central section of the mountain, which is crossed by the road from Middletown to Capon Springs, the sandstone anti-

cline is itself cut through, and the crags that overhang the road on both flanks of the mountain are only the piers on which rested the arch. It spanned the valley of Paddys Run, that now lies in the back of the mountain.

Mountains of this oval type, *anticlinal mountains*, are sometimes isolated from all other elevations by surrounding valleys. In other instances they lie *en échelon*, connected by a transverse divide much lower than their summits; or, again, two of them may coalesce at one end, forming a higher, broader summit than either possessed alone.

The canoe valley or synclinal valley may, as has already been stated, form the summit of a long, narrow mountain, which is then called a synclinal mountain. The arch mountain or anticlinal mountain may, conversely, not only include a small anticlinal valley in its crest, as Paddys Run Valley lies in Great North Mountain, but the height of the mountain may be replaced by the hollow of the anticlinal valley. This occurs through the gradual expansion of the valley from the crest of the arch toward the sides and toward the ends, so that the lowest parts of the long, narrow dome alone remain. These then stand as mountain walls inclosing the valley, from which there may be but one gateway leading out.

Such an anticlinal valley is Kishicoquillis, in Mifflin County, Pennsylvania. Stone Mountain on the northwest, and Jacks Mountain on the southeast, completely isolate it, except for Logans Gap in Jacks Mountain, near Lewiston,—a picturesque gorge through which Kishicoquillis Creek dashes. Passing through this ravine into the valley, the observer finds all the characteristics of the Great Valley reproduced. The stream flows in a channel which is cut deeply into the general surface. Ascending to what appears from below to be a hilltop, it is found to be only the general level of the valley floor, which represents a former plain. The encompassing ridges are level-crested. Toward the southwest they converge to the apex of an acute angle. Across the northeastern end of the valley they are connected by the zigzag summits of Buffalo Mountain, which resemble the environing ridges of the anthracite basins.

The anthracite basins are canoe valleys, but they lie high up above the channel of the Susquehanna, which receives the creeks that drain them. They are therefore *canoe-valley mountains* or *synclinal mountains.* Their topographic character is apparent in

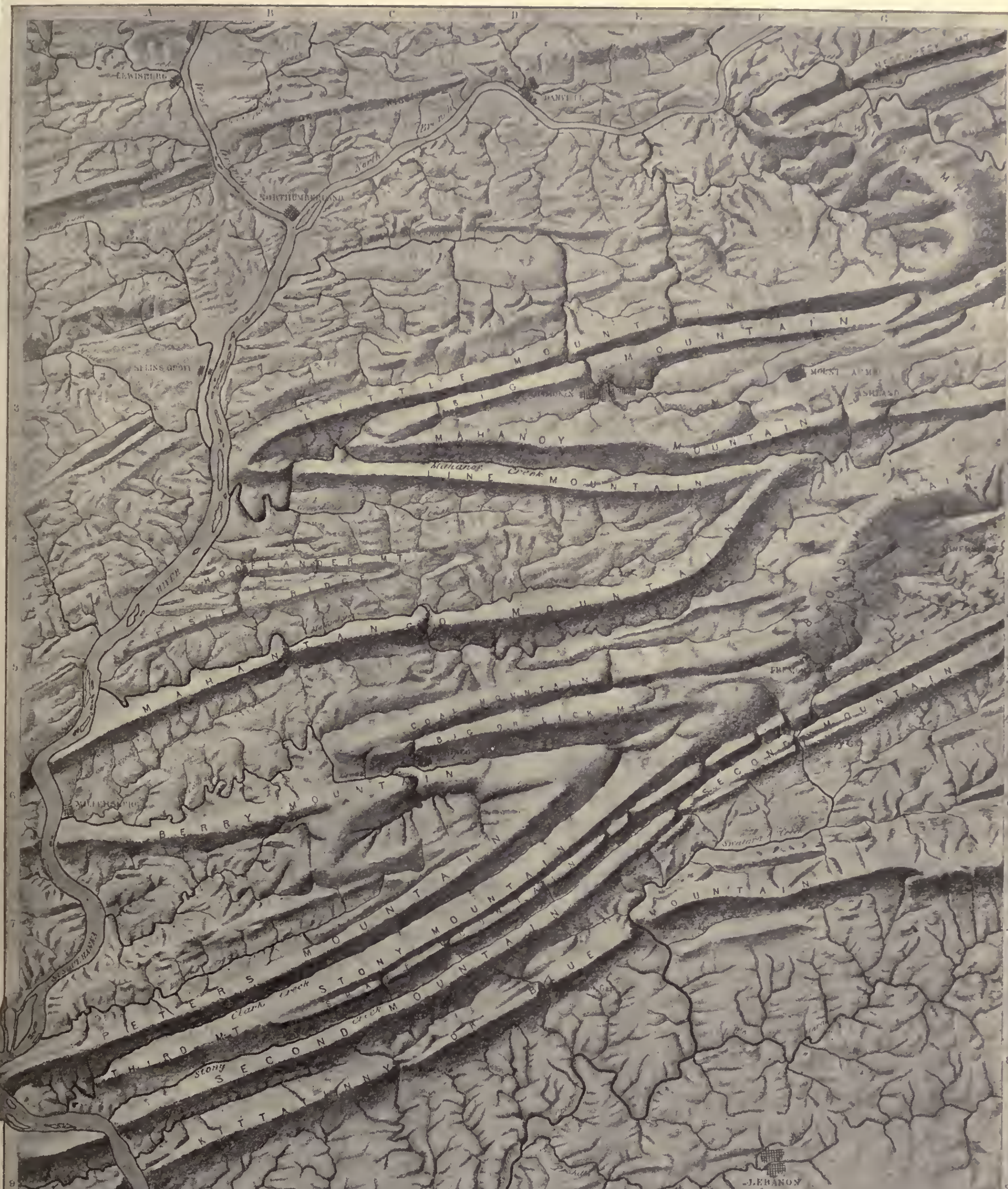
the accompanying relief map of part of eastern Pennsylvania. Referring to the extreme northeast corner, we see Nescopeck Mountain extending southwest to Catawissa Mountain. Their junction is the western prow of a canoe valley which a few miles east contains the Northern Middle Anthracite Basins.

Catawissa Mountain passes in a gentle arch into Little Mountain, which forms with Line Mountain a second canoe; that is to say, the bed of hard sandstone forming Little Mountain and Line Mountain is continuous, like the bottom of a canoe, beneath the space between them. Within this trough lies a second, which is narrower and shallower, being represented by Big and Mahanoy mountains; and within lie the coal beds of the Shamokin Anthracite Basin.

Mahantango and Berry mountains, Peters and Second mountains, form the outer rims of two convergent canoes. Coal and Lick mountains, Stony and Sharp mountains, are paired as the inner troughs, within which lie the coal-bearing measures. Eastward from Tremont these two basins become one, which extends beyond Pottsville to Mauch Chunk.

The preservation of the stores of coal contained within these basins is due to their environing ridges. The soft strata of the coal measures had been worn down to the level of the Lebanon Valley, and a very large proportion of the coal had been swept away to the sea; but these walls of hard sandstone withstood the effect of erosion, and maintained the coal-bearing mountains.

The simple monoclinal ridge which has been described is the typical but not the more common form of the Appalachian ranges. They become complex by association of parallel ridges. Thus on the inner slopes of Jacks and Stone mountains, about Kishicoquillis Valley, there is a very marked bench or terrace, which appears as a broad step in the mountain slope. In other localities, when the outer edge of such a terrace is higher than its surface nearer the mountain, there are narrow ravines separating the terrace edge as a low ridge more or less distinct from the mountain itself. The rivulets which gather in these ravines occur opposed in pairs, like opposite leaves on a stem, and their united waters flow at right angles to the trend of the main ridge through gorges in the lower ridge. Elsewhere, again, although cut through by many streams rising on the main divide, the subordinate ridge may stand at a level equal with the continuous crest, and it then appears as a distinct monoclinal ridge. On the



Relief Map of Western Portion of the Anthracite Basins, Pennsylvania, showing Canoe Valleys and Mountains and the Course of the Susquehanna across them.

south side of the anthracite basins there are three such crests, which are nearly parallel, and are called First, Second, and Third mountains; and there is also Fourth Mountain, locally so called, but it is in fact the continuation of Third Mountain on the northern side of a canoe valley.

In order that we may understand why these ridges exist, why they vary in form, and why they pursue such curious zigzag courses, we must observe the rocks of which they are composed. In the crests of nearly all Appalachian ridges occur quartz rocks of one variety or another. The rock may be a conglomerate of white pebbles, or a sandstone of coarse or fine grains, or a massive rock called quartzite, breaking into sharp fragments; but quartz is the predominating mineral. Of all common minerals, quartz is the hardest and least soluble: therefore the quartz rocks longest resist the action of the atmosphere in wearing and dissolving them. Lime, on the other hand, is dissolved with relative rapidity: therefore lime rocks, such as marble, limestone, and limy mud rocks, decay quickly in a moist climate like that of the Appalachians; the lime being leached out, and red clay remaining.

These two classes of rocks, quartz rocks and lime rocks, form the Appalachian region between the Blue Ridge and the Alleghany Front. There are many varieties, differing in composition, texture, and color; but they all fall into the two great classes of the quartz rocks and the lime rocks,—the relatively insoluble and the more soluble. The soluble lime rocks occur in the valleys and lower slopes of the ridges; the insoluble quartz rocks form the ridge crests.

The quartz rocks extend as beds of conglomerate, sandstone, or quartzite between the much thicker beds of lime rocks. These beds vary in thickness from a few inches to hundreds of feet, but a single stratum of solid quartz rock more than 300 feet thick is unusual. They extend downward from the surface at different inclinations in different districts. In the Alleghany Front they lie almost flat. Their edges make the eastern slope of the mountain, and the uppermost one forms the surface of the plateau descending gently westward. On the other hand, in Kittatinny Mountain, near Harrisburg, the beds stand vertical.

The form of the cross section of any ridge depends upon the inclination of the beds of which it is composed. Where the strata are gently inclined, the height approaches more or less

nearly to the character of a table mountain. In the steeper slope the edges of the beds are exposed. As the soft beds wear away, the harder beds, being undermined, break off in blocks, and a bold front remains. Where the base material accumulates, the rock face is masked, and cliffs are visible only toward the summit. Where the strata, on the other hand, are steeply inclined, the edge of the hardest bed makes the crest of the mountain, and more or less symmetrical slopes are worn from the adjacent beds.

INDEPENDENCE OF GREAT STREAMS AND GREAT VALLEYS.

Two rivers, rising in the Alleghany Plateau far west of the Alleghany Front, and joining in the heart of the valley ridges of Pennsylvania, form the Susquehanna. Their courses to their junction lie across many mountains; and the lower course continues in the same manner across mountains, even though an easier route over plains was near at hand. This is well illustrated in the channel of the Susquehanna above Harrisburg, as shown in the map, pp. 170, 171.

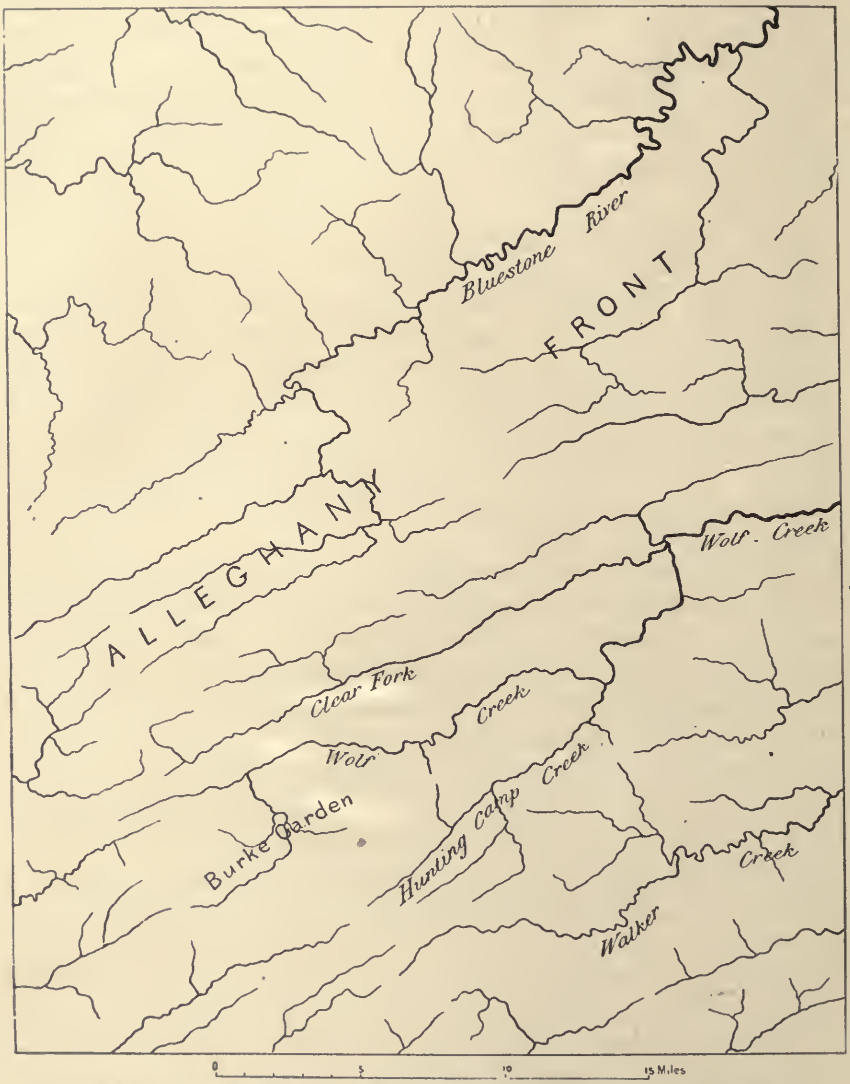
The head waters of the Potomac lie in the plateau west of the Alleghany Front. Large tributaries running northeastward in the valley join it; and the principal one of these, the Shenandoah, is the largest river north of Tennessee flowing in the direction of the length of the Appalachian Valley. But all these waters assume in the Potomac a southeasterly channel, which is cut across the hard beds of the valley ridges.

New River, which gathers its waters in North Carolina, does not follow the line of easy descent northeastward along the Great Valley to the Potomac or Susquehanna. It chooses instead a difficult way to the Ohio River across the Greater Valley and the Plateau.

These are examples of the general fact that the streams of the Appalachian ranges are not controlled by the mountains. The ridges pursue their courses, and the streams passing across the ridges pursue independent courses. The discordance is one of the most marked features of the topography, and it gives rise to many picturesque water gaps. As we shall see farther on, it is due to the fact that the transverse river channels are older than the valley ridges.

Within the Valley the brooks and creeks have arranged

themselves usually in systems of pairs. Flowing southwest, a brook meets its fellow running northeast, and together they turn southeast or northwest to traverse a ridge. In the valley be-



Types of Drainage resulting from Adjustment to Beds of Hard and Soft Rock.

In the northwest corner of the map the streams flow diversely over rocks which lie in horizontal beds. On the head waters of Bluestone River and Wolf Creek the branches are adjusted to tilted hard and soft beds, forming an example of "trellised" drainage. Between Wolf and Hunting Camp creeks is an anticlinal arch, Burke Garden, and the systems of streams define its position. Walker Creek and its branches also flow across tilted beds, but, as they are more homogeneous than those along the heads of Wolf Creek, the streams are less systematically adjusted.

yond the ridge they are joined by a pair similar to their own courses before their union. Beyond a second ridge or a third, the growing creek may for a time flow northeast or southwest, but it will presently pass out by another water gap. Ultimately it falls into one of the great transverse rivers. This arrangement of parallel brooks, which swell the volume of a creek generally flowing at right angles to their courses, resembles a vine from whose central stem branches are trained on a trellis. It is sometimes called the *trellis* or *grapevine system.*

Although most conspicuously developed in the Appalachians, this trellis system of drainage is common in regions where beds of hard rock lie steeply inclined to the general surface. The parallel branches of the system are controlled by the parallel ridges between each two pairs. Thus it appears that the hard rocks have to this extent influenced the arrangement of the streams.

HOW THE APPALACHIAN UPLIFT HAS BEEN SCULPTURED.

We have observed that the rivers flow in channels, which, like the gullies they resemble, have been cut by swift-running waters. We have noticed also that waters running less swiftly deposit mud, building flood plains or bottom lands. These two processes are as old as rivers and the force of gravity. In the course of ages they will remove mountains and spread plains. Let us trace their work.

Streams which carry sediment cut like a saw. Like a circular saw, they file continuously into the mass opposed to them. This is the mass of land above sea level, and they saw their channels from their mouths backward into it. Thus every stream tends to cut its channel throughout its entire course down to the level of its mouth. But in this tendency it is checked when its fall becomes so gentle that it deposits sediment. Then it can no longer cut downward, but it begins to carve sidewise.

By depositing sand or mud, a stream builds bars, from which it swings off against its bank. Undermining this, it is deflected toward the other bank, which it may strike and undercut in turn. Thus, when a river has filed its channel downward to a gentle slope on which it deposits sediment, it then begins to wind sidewise, and with ever-increasing crookedness widens its valley. The rock and soil which it cuts away are swept on in

flood tide, and are left by the subsiding waters, forming a flood plain. The Mississippi is thus at work.

Valleys are widened by other processes which aid the streams. By heat and cold, moisture and frost, vegetation and solution, rocks are shattered and they decay. The talus and soil remaining sink down to a slope more gentle than that of canyon walls such as streams cut in hard rocks. The loosened material creeps down the hillside. Gullies grow backward into it, and develop many arms, through which the gathered waters of a storm sweep the soil to the lowlands. Every space between the streams is attacked sooner or later, and the higher parts of the surface are graded down. The tendency is in time to reduce the land to a gently sloping plain, which extends from the sea to the head waters of the rivers. Such a plain is called a *base-level.*

The development of a base-level over a broad area requires a long time, and does not progress equally. There are many conditions that affect the rate at which the surface wastes, but that which most concerns us here is the relative softness or hardness of the rocks. In the moist Appalachian climate, other things being equal, a soft or soluble rock, like calcareous shale or limestone, wastes away much faster than harder or insoluble quartz rock, and therefore beds of the harder rock may long remain in relief above a base-level extended over the areas of softer rock.

Let us again look over the Appalachian landscape. It has certainly been sculptured by flowing water, to which the deep channels of the streams are due. Could some Titan fill these channels level with the hilltops of the Greater Valley, he would restore a plain which would extend over the area of soft rocks between the ridges of hard rocks. This is the character of a base-level, and we cannot doubt that such a plain was developed by the streams before they began to cut their present channels. Let us call this plain, which is well preserved in the Shenandoah Valley, the Shenandoah base-level.

Above this base-level the valley ridges rise 200 to 1,800 feet. Neighboring ridges are usually of nearly the same height, and their crests are often level lines, but slightly broken. Such lines are elements of a plain, and, with our eyes opened by suggestion, we may see that they do represent one. But it is only through the extensive landscape studies of Professor Davis and of Messrs. Hayes and Campbell that we are assured that the ridge tops were once even with the surface of a base-level which

was much older than the Shenandoah Plain. Let us call this older plain the Kittatinny base-level, because it is well preserved in the even crest of the long mountain of that name.

To restore the Kittatinny Plain we must fill in with many cubic miles of rock all the Greater Valley between the Blue Ridge and the Alleghany Front, at least level with the ridge crests. This done, however, we should have a broad, dome-shaped elevation 4,000 feet above the sea in southwest Virginia, and sloping gently to the Atlantic and the Mississippi.

Geologists date this Kittatinny Plain as of the so-called Cretaceous period of the earth's history. If we should compare all the ages since the beginning of rocks and oceans on the earth with all the years since human existence began, the Cretaceous period would correspond, perhaps, with the Roman occupation of Britain. Thus vaguely we may indicate that the Cretaceous belongs to the later periods of the earth's development. But the time which has since elapsed has been sufficient for the growth of the Appalachian uplift, and the erosion of its valleys and ranges. From what we have seen in the landscape, we may reconstruct an outline of this growth.

A base-level is the lowest slope to which rivers can reduce a land area. With one margin it touches the sea, from which it rises imperceptibly. Unless it be very old and very completely planed, hills may survive at some distance inland, or over areas of the hardest rocks. Such a surface, which is almost, but not quite, a base-level, is called a *peneplain.* On such a surface the rivers meander in wide oxbows throughout their valleys. There are no marked divides. Under these conditions, the channels of rivers are unstable features, as is that of the Mississippi or the Missouri; and, the fall of a river or system of rivers being very slight, a moderate tilting of the land surface may suffice to change the courses of streams very greatly, or even cause them to flow in a reversed direction. The Kittatinny peneplain was very extensive, and almost completely planed. The only heights in the Appalachian region were hills which are now the mountain summits of western North Carolina, but were then at a lower altitude. The land was flat, featureless, and very slightly elevated above the sea. The courses of the streams had been adjusted during the long period of erosion; and the five rivers flowing eastward had assumed that course in consequence of a tilting of the land toward the Atlantic, which caused them to

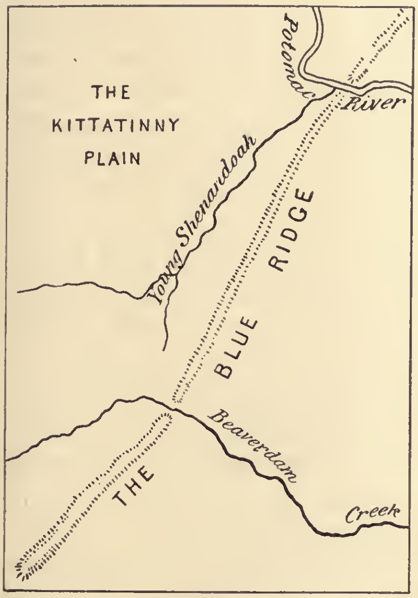
reverse their courses, which were formerly northwestward. New River did not share in this reversal, and remains to record the original slope from an eastern continent toward an interior sea. From this condition began the growth of the present Appalachian Mountains.

Along a zone corresponding with the present Great Valley the earth's surface rose unequally and very slowly to a maximum height of about 1,400 feet in central Virginia. The elevation grew very gradually, sloping to east and west, and to the Gulf of St. Lawrence on the north, as well as to the Gulf of Mexico on the south. Upon the surface of this broad dome the Susquehanna, Potomac, James, Roanoke, and New rivers meandered in courses closely coincident with those they now possess. They had assumed these courses on the Kittatinny base-level, where the beds of hard and soft rock of the Appalachian ranges were buried beneath the alluvium of their flood plains. As the base-level swelled upward, the rivers descended to the sea with swifter flow. They resumed the work of cutting their channels vertically, as they had done before the Kittatinny Plain was base-leveled, and, removing the mantle of alluvium, they discovered the solid rock ribbed with beds of sandstone and quartzite. Their courses lay across these beds; and, although lines of easier channel cutting lay along the outcrops of soft beds, the great rivers could only persist in their channels, which they corraded as rapidly as the hard beds rose athwart their course. The water gaps by which these rivers pass across the ranges, such as that at Harpers Ferry, and those on the Susquehanna above Harrisburg, and that on the Delaware near Stroudsburg, are the result of the rivers' sawing.

On the Kittatinny Plain many smaller streams flowed across the ranges; and they also, persisting in their courses during the upheaval, cut water gaps in the hard beds. But they could not deepen the gaps as rapidly as did the great rivers, and the work of the smaller streams is now represented by the notches in the ridges high above the Shenandoah Plain. No streams now flow through these little V's: they are *wind gaps* from which a rivulet descends on each side of the ridge. Further explanation is necessary before we can understand how this change has come about, but a discussion of a single instance will make it clear.

The Potomac traverses the Blue Ridge at Harpers Ferry. South of this water gap are several wind gaps, such as Snick-

ers Gap, which mark the channels of ancient streams, now diverted. The Shenandoah River enters the Potomac above the water gap at Harpers Ferry, flowing northward along the



Arrangement of Streams on the Kittatinny Plain.

Adjusted Streams on the Shenandoah Plain.

Methods and Results of River Piracy.

western base of the Blue Ridge. The streams which passed through Snickers Gap and the other wind gaps ran above the present course of the Shenandoah, crossing it about at right angles. The two drainage systems could not exist at one time: therefore it is evident that the older one has been replaced by the younger river, the Shenandoah. This diversion took place by the gradual growth of the Shenandoah from its mouth southward. The Potomac, the large stream, cut its water gap faster than Snickers Gap was cut. The Young Shenandoah of the Kittatinny Plain, a small tributary of the Potomac where the mouth of the present Shenandoah is, acquired considerable fall as the Potomac deepened its gorge, and sawed its channel down rapidly in the limestone, which offered no great resistance. But the stream in Snickers Gap, with perhaps less fall and not much greater volume than the Shenandoah, had to saw much harder rock in crossing the Blue Ridge. Its channel remained high, therefore, as compared with that of the Shenandoah. The latter,

extending its head waters backward as a tree puts out new twigs, eventually tapped the channel of the other stream above Snickers Gap. The waters above the point of attack joined the Shenandoah; the section between the point of attack and Snickers Gap was reversed as the Shenandoah rapidly deepened the channel of its new conquest; and the lower portion of the stream, now called Beaverdam Creek, having lost its original head waters, took its rise at Snickers Gap. Thus the ancient stream which once flowed through the gap was divided into three sections,—the diverted, the inverted, and the beheaded,—while the Shenandoah, the diverter, was strengthened.

By successive captures of this kind the piratical diverter has grown, until it is now the largest of the rivers within the Valley; and its head waters approach the channel of the James, which it may in time add to its conquests.

This process of capture of a small stream by a larger one, or of a stream cutting hard rock by one making a deeper channel in soft rock, or of a sluggish stream by one having a rapid fall, takes on many aspects. It is a phase of that adjustment by which rivers tend to take the easiest route to the sea.

Furthermore, in consequence of this adjustment, streams are diverted from areas of hard rock to areas of soft rock, and the hard rocks remain as divides. Thus in the case of the Shenandoah all of the formerly independent streams which crossed the Blue Ridge are now concentrated in the channel of that one river. The combined waters are working rapidly to reduce the surface of the Shenandoah Plain, while the Blue Ridge remains subject only to the attacks of rain and tiny rills. Adjustment of streams not only establishes divides on the hard rocks, but also diverts the waters that are cutting across them.

The drainage system of the Kittatinny Plain was developed in the alluvium of the base-level. When it discovered the hard and soft rocks of the Appalachian zone, it was out of adjustment, and the streams competed for their courses after the manner described. The more powerful or more advantageously situated rivers held their own, and conquered their neighbors. Thus there are in the present drainage system the older rivers which occupied their present channels when carving the Kittatinny Plain, and the subsequent streams which developed as the upheaved plain was cut into.

When the upheaval was in progress and while it was young,

the carving was intaglio,—canyons or deep channels like those of the present landscape were sunk toward sea-level; but as the streams became adjusted among themselves and to the ranges of hard and soft rocks, and their fall lessened, they began to widen their valleys. In course of a long time they carved out the Greater Valley, leaving the ridges of hard rock in relief, to record in their level crests and wind gaps the extent of the Kittatinny Plain and the direction of its drainage.

The arching of the somewhat corrugated dome which brought about the adjustment of the streams probably went forward steadily, though gradually. It ceased, and for a relatively long period the Appalachian uplift remained about constant in elevation. The adjusted rivers in their lower courses constructed flood plains, which spread toward the head waters as the valleys were cut more deeply. A base-level plain was extended throughout the valley from the great rivers back to the slopes of the ridges. It is now represented in the general level which we have called the Shenandoah Plain.

The Shenandoah base-level is less extensive than the Kittatinny was. It is limited to areas of the soft rocks. With these it is coextensive, and the period of its development was so long that all the areas of soft rocks, even to the head waters, were planed; but it was cut so short that none of the ridges of hard rock were anywhere leveled.

The swelling of the Appalachian dome began again. It rose 200 feet in New Jersey, 600 feet in Pennsylvania, 1,700 feet in southern Virginia, and thence southward sloped to the Gulf of Mexico. Its vertical arcs are from the Mississippi to the Atlantic, from Nova Scotia to the Gulf. The axes of greatest uplift lie along the central valley; but their relations are not simple, and the study of their details involves problems of stream adjustment which are of deep interest.

In consequence of the renewed elevation, the streams were revived. Once more falling swiftly, they have sawed and are sawing their channels down, and are preparing for the development of a future base-level.

In the valleys powerful rivers are planing soft rocks. Along the ridge crests weak rivulets attack, but do not much affect, the masses of hard quartzite: therefore the ridges are being left in even higher relief,—the Appalachian ranges are becoming more acute.

GENESIS OF THE APPALACHIAN TYPE OF MOUNTAINS.

Narrow valleys and linear ridges, arranged in more or less complex relations, are often described as being of the Appalachian type; not because such ranges are uncommon features of the earth's surface, but because nowhere else in the world is this form of topography so characteristically and extensively developed. Nevertheless monoclinal ridges and streams adjusted to longitudinal and transverse valleys, associated with synclinal and anticlinal valleys or mountains, are found in all mountain systems except those which are composed mainly of volcanic or massive igneous rocks. We may recall the fact that the Appalachians are formed of *beds* of rock,—of hard and soft beds occurring in alternation and inclined at angles varying from the horizontal to the vertical,—and we should not expect to find this type of topography developed in masses of homogeneous granite, such as that which constitutes Pikes Peak or the southern part of the Sierra Nevada.

Bedded rocks are produced by various agencies,—by successive eruptions from volcanoes, by winds, by flood waters of rivers or from melting glaciers, and by deposits of sediments beneath lakes and seas; but of the deposits thus formed only those which accumulate beneath somewhat extensive bodies of water are sufficiently regular in bedding to develop into ranges of the Appalachian type when upheaved; and of such marine formations, only those which are so bent, during upheaval, as to present their upturned edges to erosion, develop the Appalachian type of topography.

As illustrations of these facts we may refer to the foothills of the Rocky Mountains, where the "hog-back ridges" are typical forms; or in Europe to the Jura Mountains and other outlying ranges about the Alps, which present very striking examples of monoclinal, synclinal, and anticlinal features.

Beds of sediment which are spread beneath the sea consist of gravel, sand, and clay, together with lime, and many other substances in smaller proportions. All of these materials are brought to the sea by rivers flowing from more or less extensive land areas, or are gnawed from the shores by waves and carried out to sea by the undertow. A bed of sediment is spread, it is buried beneath another bed of similar or different sediment, which in turn is itself buried: and the layers harden into rock,

forming, of sand, sandstone; of clayey mud, shale; and of limy ooze, limestone.

This process of deposition goes on for ages. The materials vary in character according to conditions both on the land and in the sea. The strata become perhaps several thousand feet thick. They sink somewhat into the earth's mass; so that the sea, though receiving great volumes of land waste, remains deep. But after ages of subsidence, forces within the earth, whose origin and character are unknown, reverse the movement, and raise the sea bottom to form dry land. The strata may be simply upheaved and tilted from their original horizontal position, or they may be compressed by a force of inconceivable power which gradually bends them into corrugations that consist of successive arches and troughs.

This upheaval is the birth of a range of the Appalachian type. In a short time, as the earth's ages are counted, streams cut canyons in the newly exposed surface; in the process of adjustment to hard and soft rocks, piratical brooks grow to the stature of rivers by the capture of less favored streams; through the resistance of hard strata, ridges develop and become prominent; but in time the surface is reduced to a peneplain, and the rivers, meandering broadly in their extensive flood plains, are liable to great changes of course in consequence of gentle tipping of the land. During a subsequent age the subterranean forces may again act to upheave the land; the rivers are then revived, and begin anew the process of degradation, which ceases only when the monotonous base-level is extended over the land. The process includes the development and the wasting-away of a generation of ridges, and thus generation after generation may succeed one another as often as the earth's surface rises higher than the level of a peneplain.

Such has been the genesis and history of the Appalachian ranges.

During the Paleozoic era, an era long prior to the development of the Kittatinny Plain, a seashore extended where now the Blue Ridge rises. It was not the Atlantic coast of a smaller North America. It was the western coast of Appalachia, a continent which lay between an interior sea on the west and the Atlantic on the east. Beneath the interior sea were deposited sediments, which formed the beds of rock now found in the Appalachian ranges. In the movements of the earth's rocky

envelope the strata between the Blue Ridge and the Alleghany Front have been bent and upturned. Their edges are now exposed throughout the Greater Valley. But the zone in which the beds are thus steeply inclined extends from the Blue Ridge westward only so far as the Alleghany Front. In the Front itself and in the plateaus west of it the strata approach a horizontal position. The steep face of the Front, which is turned eastward, presents to view the edges of the flat beds.

In enumerating the principal features of the Northern Appalachian ranges we distinguish three,—the Blue Ridge, the Greater Valley, and the Alleghany Front. We now see that these three divisions are genetically related, and owe their characters to geographic conditions that no longer exist. The Blue Ridge is part of the ancient continent of Appalachia, which, being composed of hard but generally homogeneous rocks, maintains a mountain range whose forms are rounded. The Greater Valley corresponds to a zone along the shore of the ancient sea, where the littoral formations consisted of alternating beds of sandstone, shale, and limestone. These beds have been bent into arches and troughs, and in process of erosion their edges have developed as linear valleys and ridges. The Alleghany Front is simply the edge of the plateau, the edge of the region of nearly flat-bedded rocks which have been raised without marked bending. The three constitute a group, in which the Blue Ridge may be called a *continental range;* the Greater Valley, a *tilted littoral zone;* and the Alleghany Front, which confronts the old continent of Appalachia, an *inland-facing escarpment.*

These names imply a recognition of seas and shores that have vanished, and which were not fixed features even of the earlier geographic conditions. Shores are shifting lines, and migrate back and forth over land surfaces. But the three great topographic divisions of the Appalachians may nevertheless be classified according to the conditions in which they originated. Thus considered, the Appalachian ranges are found to be a remarkably complete development of a type whose homologues are distributed in all continents.

INFLUENCE OF THE APPALACHIANS ON SETTLEMENT.

The Appalachian ranges lie between zones of plateaus. On the east and southeast are the Piedmont Plateaus, and on the

west and northwest are the Alleghany Plateaus. Beyond these zones respectively lie the Atlantic Coastal Plains, and the Prairie Plains, bordering the Mississippi Valley.

The plains were the homes of the most populous Indian tribes, and they were first settled by the invading Spanish, English, and French. The ranges of the mountains separated these peoples, and were a barrier to intercourse long after the several topographic provinces had come under one national government, and their inhabitants had become one nation.

In this connection it is desirable to note certain characteristics of the Appalachians, bearing upon their effectiveness as a barrier. The ranges are marked by great length. They are continuous along hundreds of miles. Like a series of gigantic walls, they lie athwart the path of one who travels northwestward. They are pierced, it is true, by numerous passes,—the water gaps,—but the gaps through the successive ridges are not opposite one another, and they resemble rather breaches choked by débris than open gateways.

Before the days of railroads, or even of graded highways, the migrating Indian, or white man, made his way on foot, on horseback, with pack horses, or by canoe. On the hunt and in warfare he went unencumbered, and took little note of natural obstacles. To break through the underbrush, to climb among fallen trees and rocks, to ascend steep mountains, or to carry the light canoe around rapids, was the hunter's, the warrior's, accustomed task. But the family or the tribe, conveying household goods, found thickets, windfalls, steeps, and cataracts most serious impediments to their progress, and they were controlled in the direction of their migrations to a great extent by the ease or difficulty of journeying; and this was more especially the case when the best hunting grounds or best farming land lay along the easiest route.

All the natural conditions which govern the welfare of a people inhabiting a district depend more or less upon the topography. The flora, fauna, water supply, healthfulness, attractiveness, and accessibility are conditioned by the nature of the soils, the evenness or ruggedness of the surface, the elevation above sea, and the distribution of streams. The four great districts of the Appalachians—the Great Valley, the Blue Ridge, the Alleghany Ridges, and the Alleghany Plateaus—differ in all these respects.

The Great Valley is by nature adapted to be the home of a dense population. It has harbored many peoples, who have warred for its possession. It was a natural route along which tribes wandered from the pine or hardwood forests of the North to the cane-brakes of the South, or *vice versa*, and from which there was intermigration and commercial intercourse with the dwellers along the coast.

The study of the distribution of Indian languages, and of the ancient village sites, shows that probably two great waves of migration, and perhaps more, passed through the Valley before Columbus landed. The Algonquins, spreading from their homes about the Lakes and the St. Lawrence, pushed far to the southward, and, as fishermen and crop raisers, made their homes wherever fish were abundant or the soils fertile. Behind them and at a later period came the warlike tribes of the Iroquois, the most progressive of the Indians of eastern North America. The Iroquois of the Six Nations drove the Algonquins westward; and the Cherokees, also a branch of the Iroquois, occupied the Appalachians southward to Tennessee and Georgia. There they were overpowered by the Watauga men under John Sevier, and driven to the Carolina mountains, where a remnant of the tribe still exists. The rising power of the Six Nations was likewise destroyed; for their home in northern New York lay in the path of both French and English, and they were drawn into the wars which foreigners waged for lands that belonged to the Indian.

The immigration of the whites was directed by the natural highways, and limited by the mountain barriers. The seafaring Dutch and English found a congenial habitat around the estuaries of the Coastal Plains. Slowly they worked their way westward. "Blue Mountain," signifying the aspect of the range from a distance, was the name they gave to the most eastern ridge; and it became so fixed during the decades which passed before they had a nearer acquaintance with the mountains, that it survives to-day in two distinct ranges,—the Blue Ridge of Virginia, and the Blue or Kittatinny Mountain of Pennsylvania.

In eastern Pennsylvania, however, the northern end of the Great Valley is easily accessible; and settlement spread into it both north and south of the Susquehanna. In Virginia the low passes just south of the Potomac afforded easier routes across the ridge than the water gap of the river itself, and they were occupied by roads along which pioneers passed into the Valley.

There Winchester was laid out as a town in 1752. It does not appear that the Virginians spread beyond the head waters of the Roanoke during the earlier immigration, the Tennessee region having been occupied from North Carolina by men who crossed the highlands of that State. The diversion of migration from the Great Valley eastward followed the natural features. On the head waters of the Roanoke two ridges rise to a height of more than 3,000 feet above the sea, between the Blue Ridge and North Mountain, and they appear so to close the Valley that the old maps show a range definitely limiting its southern extension. From this supposed mountain range, beyond which lay an unknown land, pioneers turned through the low passes of the Blue Ridge toward the Piedmont Plateaus of North Carolina.

In 1776 there was published in London the "American Atlas," engraved by Jeffreys from maps and surveys dating from 1770 to 1775. These maps present an accurate picture of the extent of settlement, so far as it is indicated by the growth of roads into the wilderness, and the existence not only of towns, but of houses which served as stopping places.

In New York the valleys of the Hudson and the Mohawk had been occupied, forming a belt more than 200 miles long from New York to the farthest outpost, which in 1775 was "Rynards, the uppermost settlement," 70 miles in a straight line beyond Albany. Eastward roads were continuous with those of New England, and towns were numerous; but west of the Hudson and north or south of the Mohawk the zone of civilization was but 5 to 30 miles wide. The Adirondacks were described as "a long chain of snowy mountains, . . . not only uninhabited, but unknown." That part of the Appalachian Valley from Rondout to Port Jervis on the Delaware, now the line of the Delaware and Hudson Canal, was developed by an "Indian Road opened in 1756," which extended to Easton and Reading. Thus the settlements were connected all along the northern and eastern sides of the Alleghany plateaus. The plateaus in southern New York and northern Pennsylvania were the "Endless Mountains," and included the "Great Swamp." The broad blank on the map which these names cover west of the Delaware is expressive of a *terra incognita.*

In Pennsylvania there were houses, mills, churches, and towns scattered throughout the region east of Kittatinny Mountain: that barrier limited their expansion. Lancaster was an

important center, connected by two roads with Philadelphia and Wilmington on the east, by three roads with points in the Lebanon Valley, and by two others with the West and South, as far as those parts of the country were then known. West of Kittatinny Mountain, however, was the labyrinth of the Alleghany ridges, through which few, save perhaps a Leatherstocking, could guide the immigrant. Roads, which no doubt followed former Indian trails, are shown here and there on the map; but it is evident, from the manner in which their courses appear to traverse the most difficult ridges, that the map maker worked without accurate knowledge, and the beautiful series of ranges that is shown on pp. 170, 171, is delineated by him as a confusion of heights. The district of the anthracite basins is marked "St. Anthony's Wilderness," but the existence of coal is noted in several places.

Southward from Lancaster the main road ran through York, by Williams Ferry on the Potomac, to Winchester; and Winchester was connected with North Carolina by a road extending along the western side of the Valley to the gap of the Roanoke in the Blue Ridge. Passing through that gap, it was continued to the Yadkin River in what is now Stokes County, North Carolina. This is marked "The Great Road from the Yadkin River through Virginia to Philadelphia, distant 435 miles." In all the fertile valley, from Winchester south, there was in 1775 but one place worthy to be named on the map, "Staunton Courthouse." Probably along this road passed Daniel Boone when his father migrated from the frontier home near Reading to another on the Yadkin, whence Boone set out in 1769 to explore the wilderness of the head waters of the Tennessee, and to penetrate along the route through Cumberland Gap to Kentucky. In thus marking out the "Wilderness Road," Boone overcame the mountain barrier which had elsewhere turned the tide of English immigration.

From the explorations of La Salle, a hundred years before Boone's, France had laid claim to the valley of the Mississippi. No mountains barred the advance of the French voyageurs, who sailed the Great Lakes, and made their way in canoes along the numerous rivers and lakes of the interior. Moreover, they adapted themselves readily to the Indian character and life, and thus in the century of skirmishing which preceded the capture of Quebec they had over the English the advantage of easy access to the interior and the aid of Indian allies.

The character of the French and Indian War was in large measure due to the separation of the antagonists by the broad wilderness of the Alleghany plateaus. Whatever blow was struck, whether it was an Indian raid upon the English, or Braddock's expedition against Fort Duquesne, was a blow at arm's length. Even if successful, it could not be followed to decisive victory. In this harassing but inconclusive warfare the English were within, the French outside, the mountain wall. Like men besieged within a fort, the English were on the defensive, while the French could never muster force enough to break in, even through such natural breaches as the valley of Lake Champlain and the Hudson.

Thus the Appalachian ranges, by confining early English immigration, gave those colonies strength, and by excluding organized attacks protected them. But toward the close of the eighteenth century the dividing ranges separating the English on the east from their countrymen on the west became a source of weakness.

In the years succeeding 1780 many thousand men, women, and children crossed the Alleghanies to Kentucky. They went by three routes, two of which met at Fort Duquesne (now Pittsburg), whence the journey was continued by boat down the Ohio. The northern road from eastern Pennsylvania crossed the Susquehanna at Harris's Ferry (now Harrisburg), passed along the Valley through Carlisle to Shippensburg, and thence wound through the Alleghany ridges past Bedford. Ascending to the summit of the Alleghany Front, the road thence followed the highland between the waters of the Youghiogheny on the south and the Loyalhanna on the north. Thus it avoided the deep ravines which, clogged with fallen timber, rocks, and dense growth of rhododendron, made the plateaus almost impassable. The second road ran from Fort Cumberland (now Cumberland, Maryland) across the Alleghany plateaus to Great Meadows, near the present site of Deer Park, Maryland. Thence it turned north to the Youghiogheny, and followed that stream to the Monongahela and to Pittsburg. This was the route cut out by Washington and Braddock in 1759. These were mountain roads of the poorest description. Where the natural surface was fairly hard and level, the track of one wagon was the guide of the next. In swamps corduroy made of logs loosely laid across the way formed an insecure bridge. In ravines the rocky bed of

the stream furnished the roadway. On hillsides the narrow grade became deeply gullied. At seasons they became almost impassable, except to the ready frontiersman, who could build around or bridge over deep gullies or treacherous mudholes. The third route was Boone's "Wilderness Trail" through Cumberland Gap. Available only for pack trains, not for wagons, and, like the Ohio route, open to Indian attack, it was less used, though even along its rugged way many passed to join in building up the new State in the West.

The men of Kentucky were strong, determined, and independent. They were separated from their kindred of the eastern seaboard by diversity of interests as well as by natural obstacles. Their prosperity depended on the commercial freedom of the Mississippi even more than that of the eastern communities depended on free commerce in the Atlantic ports. But the politicians of the settled States were inclined to treat lightly the interests of the remote pioneer settlements, and especially to consider the navigation of the Mississippi as of little importance. Hence from 1784 to 1788, during the negotiations with Spain in which she claimed the right to control the Mississippi, the allegiance of Kentucky to the United States was severely strained. Movements toward separation were considered. Had they been carried out, the division of the country would have been due in large measure to the broad wilderness which made the communities of the East strangers to those of the West. The Alleghany plateaus formed a natural barrier along which the States might have divided.

During the closing years of the eighteenth and the earlier decades of the nineteenth century, projects of internal improvement related chiefly to the building of roads and canals to overcome or lead around the mountains.

Pittsburg remained the center of trade from the East to the Southwest, but as late as 1811 the principal route for traffic was through the Mohawk Valley by flatboats and wagons. Not until that year did Pennsylvania rouse to the importance of building a turnpike from Harrisburg to Pittsburg.

At the present time we traverse this distance in about nine hours. Railroads have penetrated the heart of the plateau region, and beyond the railroads tramways extend to the most remote recesses. The object of their construction is to develop the natural resources of the forests and of the rocky strata.

NIAGARA FALLS AND THEIR HISTORY.

By G. K. Gilbert.

Fig. 1.—American Fall from below.

The great cataract is the embodiment of power. In every second, unceasingly, seven thousand tons of water leap from a cliff one hundred and sixty feet high, and the continuous blow they strike makes the earth tremble. It is a spectacle of great beauty. The clear, green, pouring stream, forced with growing speed against the air, parts into rhythmic jets which burst and spread till all the green is lost in a white cloud of spray, on which the rainbow floats. Its charms are the theme of many a gifted bard and artist, but the fascination of its ever-varied yet continuous motion, and the awe that waxes rather than wanes with familiarity, are not to be felt at second-hand; and so the world, in long procession, goes to see. Among the multitude there are some whose appreciation of its power has a utilitarian phase, so that they think most of the myriad wheels of industry its energy may some day turn; and there are a few who recog-

nize it as a great natural engine, and in its activity and its surroundings see an impressive object lesson of geographic progress. Its æsthetic and utilitarian aspects need no expounder, but its geographic significance is too little appreciated. This paper endeavors to tell in simple language some of the lore of the professional geographer and geologist, in order that the layman may gain pleasure not only from the beauty and grandeur of the scene, but through understanding its meaning as a part in the great drama of nature.

Nature is full of change. The bud we saw yesterday is a flower to-day; the leaf that was broad and green in summer, in autumn is shriveled and brown; the bush we knew in childhood is now a broad, spreading tree. Such changes are easily seen, because they fall within the span of a man's life, and so the principle of perpetual progress in the organic world is familiar to all. Progress in the inorganic world is so slow that it is less easily seen, and there is a widespread impression that the hills are everlasting and unchanging. This impression is false. Not only hills, but mountains, plains, and valleys, are perpetually acted on by heat and cold, sunshine and rain, wind and stream, and are gradually changed. Not only do they now undergo change, but by such agents each feature was originally formed, and by such agents it will eventually be transformed into a feature of different type. Thus every element of the landscape has an origin and a history. To relate these is to explain it. This monograph may be regarded as an explanatory account of Niagara Falls and the associated natural features.

THE DRAINAGE SYSTEM.

The drainage system of the St. Lawrence is of exceptional character. In most regions the freshly fallen rain gathers into rills; these, as they run, join one with another, making brooks; brooks are united into rivers; and rivers flow to the sea. In all its journey from the hillside to the sea, the water moves forward without halt. This uninterrupted journey is rendered possible by a wonderful adjustment of slopes. The channel of the rill slopes toward the brook, the bed of the brook slopes toward the river, and the river bed slopes toward the sea. Impelled by gravity to flow downhill, the water moves continually forward from the beginning to the end of its journey. In the drainage

district of the St. Lawrence there is no such continuity of slope. The district is composed mainly of a group of great basin-like hollows, in each of which the surface slopes toward some central point, and not toward the mouth of the river. Each basin is filled with water to the level of the lowest point of its rim, and each of the lakes thus formed is a storage reservoir receiving a group of streams from the surrounding country, and pouring an even discharge over its rim to one of its neighbors. Lakes Superior and Michigan discharge to Lake Huron; Huron overflows to Erie; and Erie, having thus received all the outflow of the upper and greater lakes, sends its surplus through the Niagara to Ontario. The Niagara River is thus, from one point of view, a strait connecting two inland seas; from another point of view, it is a part of the St. Lawrence River,—the part connecting two great expansions. Viewed either way, it departs so widely from the ordinary or normal river that its name is almost misleading.

In a normal drainage system the slope is not everywhere equally steep: it is gentler in the bed of the main stream than in the beds of tributaries, and it varies from point to point so that the current, especially at low water, shows an alternation of rapid and quiet reaches. The streams of the Laurentian system not only exhibit these alternations, but have many cataracts where the water cascades down a rocky stairway or leaps from the brink of a cliff.

A normal river receives most of its water directly from rain or melting snow, and varies with the season, swelling to a flood in time of storm or at the spring snow melting, and dwindling to relative insignificance in time of drought. The water of Niagara comes only remotely from storm and thaw. The floods of the tributaries are stored by the lakes, to whose broad surfaces they add but a thin layer. The volume of Niagara depends only on the height of Lake Erie at Buffalo, and from season to season this height varies but little. On rare occasions a westerly gale will crowd the lake water toward its eastern end, and the river will grow large. On still rarer occasions a winter storm will so pile up or jam the lake ice at the entrance to the river as to make a dam, and for a day or two the river will lose most of its water.

A normal river, with its continuous current, rolls forward the pebbles loosened by its tributaries till they reach its mouth.

The rains that make its floods dislodge particles of soil, and wash them into the tributaries in such multitude that they discolor the water. The pebbles of its bed and the mud with which it is discolored are the river's load, which it transports from the face of the land to the bed of the sea. The tributaries of Niagara carry their loads only to the lakes, where the loads sink, and leave the water pure. Thus Niagara is ever clear. Sometimes, when storm waves lash the shores of Erie, a little sand is washed to the head of the river, and carried downstream; sometimes a little mud is washed into the river by the small creeks that reach its banks. Thus Niagara is not absolutely devoid of load, but its burden is so minute that it is hard to detect.

THE TWO PLAINS.

From Lake Erie to Lake Ontario the Niagara runs northward. The longer axes of the lakes trend nearly east and west, and the lakes lap past each other for a distance of forty miles, including between their parallel shores a strip of land about twenty-five miles wide. This strip, where the river crosses it, consists of two plains, sharply separated by a cliff or escarpment. The relations of the plains to the escarpment and to the lakes are shown by the map (Fig. 2) and the bird's-eye view (Fig. 4). The upper and broader plain has a gently undulating surface, which does not differ greatly in height from the surface of Lake Erie. Along the shore of that lake it rises in a low ridge, and there is also a gentle rise toward the escarpment. Its middle part is drained by two sluggish creeks,—the Tonawanda, flowing to the river from the east; and the Chippewa, from the west. The lower and narrower plain follows the shore of Lake Ontario, and rises gently thence to the foot of the escarpment. Its upper part is of rolling contour, like the upper plain; its lower is remarkably smooth and even, having once been the bed of a lake. The escarpment is a steep slope about two hundred feet high. Near the top it is generally a rocky

Fig. 2.—Niagara River and Vicinity.

cliff, giving a sharply defined boundary to the upper plain; at the bottom it merges insensibly with the lower plain.

These surface features are definitely related not only to the peculiarities of the river, but to the rocky framework of the country. The rocks are flat layers or strata resting one upon another, and of nearly uniform thickness for great distances. Nearly but not quite level, they slope gently toward the south; the descent, or dip, amounting on the average to thirty-five feet per mile. Their arrangement is illustrated by Fig. 3, which gives a north-and-south profile, with such a section of the formations

FIG. 3.—Profile and Section from Lake to Lake.
Vertical scale greater than horizontal. Base line represents sea level.

as might be seen if a very deep trench were dug from lake to lake. The heavy line at the left, and the belt below divided into blocks, represent limestones, rocks notably hard and strong, while the intervening spaces are occupied chiefly by shales, which are relatively soft and weak. Originally all the formations extended farther to the north, but they have been worn away; and, since the soft rocks were removed more easily than the hard, the edges of the hard are left somewhat prominent. This association of hard rocks with uplands and cliffs is not rare, but is rather the rule in hilly and mountainous districts. In the last preceding monograph of this series, Mr. Willis describes the plateaus and ridges of the Appalachian district, showing how frost and storm slowly but persistently ate out the soft rocks, and the rock waste was washed into streams, till valleys and lowland plains were made.

The higher of the two limestones presented in the diagram is called the Corniferous limestone. It makes a low ridge along the north shore of Lake Erie, and dips beneath the lake. The Salina shales occupy the middle part of the upper plain, and dip beneath the Corniferous. The second limestone, called the Niagara limestone, constitutes the northern part of the upper plain, and the escarpment everywhere marks its northern limit. Its full thickness is about a hundred and forty feet, but in some places it has been greatly reduced by the wasting of its upper surface. Below it is a great series of mud rocks or shales, a

thousand feet thick, interrupted near the top by a few thin beds of limestone and sandstone. These shales occupy the lower part of the escarpment and the whole of the lower plain. Their softness and the hardness of the Niagara limestone guided the erosive agents in making the escarpment and the lower plain.

Over all this rocky foundation lies a mantle of loose material, —clay, sand, gravel, and bowlders,—collectively called the *drift*. Its ordinary thickness is thirty or forty feet; but there are places, especially on top of the escarpment, where it is nearly absent, and elsewhere it fills hollows or is built into hills with a thickness of several hundred feet. It was spread over the country after the broader features of the topography had been shaped, and the agency by which it was deposited was moving ice, as will be explained a little later.

THE RIVER AND THE GORGE.

From Lake Erie the Niagara River runs over a low sag in the ridge of Corniferous limestone. Where the current crosses this rocky barrier, it is rapid and disturbed. Thence for fifteen miles it flows above shales, but rarely touches them, the banks and bed consisting chiefly of drift. The channel is broad, and the water glides along with unruffled surface. Then, a little below the mouth of Chippewa Creek, the Niagara limestone appears in the bed, and the whole habit of the stream is quickly changed. For a thousand yards it is a broad, roaring rapid, tumbling over one ledge after another with tumultuous haste; and then it pours over a precipice to the bottom of a narrow, deep, steep-walled gorge. For seven miles it courses, with alternation of deep, boiling pools and narrow, violent rapids, through this gorge, whose steep walls of rock then turn abruptly

FIG. 4.—Bird's-eye View of the Niagara River from Lake Ontario. Beyond the Ontario shore are the Lower Plain, Escarpment, Upper Plain, and Lake Erie.

to the right and left, and merge with the face of the escarpment. Thence to Lake Ontario the width is moderate, and the current is strong and deep between steep banks of red shale capped with drift.

Thus for two thirds of its journey across the upper plain the river travels on top of the plain, and then for the remaining third it runs from two hundred to three hundred feet below the plain in a narrow trench. This contrast is the geographic fact on which scientific interest in Niagara has centered, and its importance is not readily overestimated.

The walls of the trench are vertical cliffs in their upper part, and are there seen to be composed of the same limestone that underlies the plain. The limestone cliffs are of moderate height,

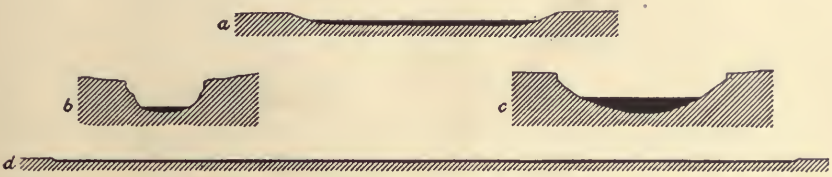


FIG. 5.—Cross Sections of Niagara River.
a, two miles below the escarpment; *b*, in the narrowest part of the gorge; *c*, in a broad part of the gorge; *d*, two miles above the falls. Scale, about 2,000 feet = 1 inch.

and from their base there usually starts a talus or apron of fragments, which descends to the river's edge. The general appearance of the gorge is fairly illustrated by the view in Fig. 7. Here and there the talus is scant or altogether absent, so that the strata can be seen; and wherever they can be seen, examination shows the two sides to have the same beds, in the same order, and at the same heights. First come gray shales about fifty feet thick; then a blue-gray limestone full of fossil shells, and ten or fifteen feet thick. This is the Clinton limestone of geologists; and it is so firm, as compared with the beds immediately above and below it, that rain and frost have affected it less, and it projects beyond its neighbors. There are several places where the edge of the bed is a cliff, though the adjacent shales are covered by fallen fragments (Fig. 6). Next below are green-gray shales, with thin limestone beds, and a soft, gray sandstone, the whole occupying a vertical space of about thirty feet; and then the color changes to a bright red, which characterizes the lower beds. These are chiefly shales, but there are soft sandstones among them; and there is one hard sandstone bed, of a pale

gray color, which stands out prominently like the Clinton limestone, and for the same reason. It is twenty feet or more in thickness, lies one hundred and twenty feet below the Clinton limestone, and is called the quartzose sandstone (see Figs. 10 and 21). The observer who sees these various rocks, hard and soft, gray and red, matched bed for bed on the opposite sides of the

FIG. 6.—Cliff and Talus of American Bank above the Whirlpool.
The Niagara limestone appears in the upper cliff; the Clinton, in the lower. The quartzose sandstone is not seen, being below the water.

gorge, and who studies them at the angles of the walls, so as to realize that each is a great level plate, which, if continued through the air, would bridge the chasm to its companion in the opposite wall, never doubts that the rock beds were originally continuous, and that the gorge is of later origin. As to the way in which the gorge was made, there has been some difference of opinion. One or two writers have thought it was a crack of the earth violently rent apart, and one or two others have thought it was washed out by ocean tides; but the prevailing opinion is that it was made by the river that flows through it, and this opinion is so well grounded that it is hardly worth while to consider its rivals in this place. The agency of the river is shown by the modern recession of the cataract, by banks, terraces, gravels, and shells, marking earlier positions of the river bed, and by a cliff

over which part of the river once poured as a cataract. It is qualified by a buried channel belonging to an earlier and different system of drainage. As these evidences are intimately connected with the history of the cataract and river, they will be set forth somewhat fully.

THE RECESSION OF THE CATARACT.

Modern Recession.—The cataract is divided unequally by Goat Island. The part on the southwestern or Canadian side is the broader and deeper, and is called the Horseshoe Fall; the

Fig. 7.—The Gorge below the Whirlpool, with Part of the Whirlpool in the Foreground.

other is the American Fall. As shown by the map (Fig. 15), the Horseshoe Fall is at the end of the gorge; the American, at its side. The cliff over which the water pours is from one hundred and forty to one hundred and seventy feet high, measured from the water of the river below. It is composed of the Niagara limestone at top, from sixty to eighty feet thick; and the shales,

etc., beneath, as already described. At the edge of each fall, where one can look for a distance under the sheet of descending water, the limestone projects like a cornice beyond the wall of

Fig. 8.—The Horseshoe Fall, from the Canadian Bank.

shale; so that there is a strip of the upper rock which is not directly supported by the lower, but is sustained by its own strength. From time to time portions of this cornice have been seen to break away and fall into the pool of water below, and other fallings have made themselves known by the earth tremors

Fig. 9.—The American Fall, from the Canadian Bank.

they produced. Usually the falling masses have been large; so that their subtraction has produced conspicuous changes in the contour of the cataract, and their dimensions have been estimated in scores of feet. Nearly all have broken from the cliff under, or at the edge of, the Horseshoe Fall. As these catastrophes depend on the projection of the limestone without sup-

port, we are warranted in supposing that it is gradually deprived of support by the removal of the softer rocks beneath; and, although it is impossible to see what takes place amid the fearful rage of waters, we may properly infer that that very violence makes the cataract an engine of destruction by which the shales are battered and worn away. Under the middle of the Horseshoe, where the pouring sheet is at least twenty feet thick, its force is so great as to move most, or perhaps even the largest, of the fallen blocks of limestone, and by rolling them about make them serve as weapons of attack.

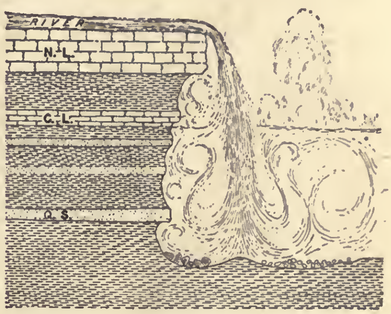


FIG. 10.—Profile and Section at Middle of Horseshoe Fall, showing Arrangement of Rocks and Probable Depth of Pool under Fall.

N.L., Niagara limestone; C.L., Clinton limestone; Q.S., quartzose sandstone. Scale, 300 feet = 1 inch.

In 1827 Capt. Basil Hall, of the British Navy, made a careful drawing of the Horseshoe Fall by the aid of a *camera lucida*. The use of that instrument gives to his drawing a quality of accuracy which constitutes it a valuable record. Sixty-eight years afterward, in 1895, a photograph was made from the same spot, and our illustrations (Figs. 11 and 12) bring the two pictures together for comparison. The bushes of his foreground have grown into tall trees which restrict the view, but the region of greatest change is not concealed. A vertical line has been drawn through the same point (Third Sister Island) in each picture to aid the eye in making the comparison. The conspicuous changes are the broadening of the gorge by the falling-away of its nearer wall, and the enlargement of the Horseshoe curve both by retreat to the right and by retreat in the direction away from the spectator. In 1842 Professor James Hall, State geologist of New York, made a careful instrumental survey of the cataract for the purpose of recording its outline, so that subsequent recession might be accurately measured by means of future surveys. His work has been repeated at various times since, the last survey being by Mr. A. S. Kibbe, assistant State engineer, in 1890. The outlines, as determined by these surveys, are reproduced in the chart on page 216 (Fig. 13), which shows that the greatest change has occurred in the middle of the Horseshoe curve, where the thickness of the descending stream is

FIG. 11.—The Horseshoe Fall from Forsyth's Hotel, 1827. (Compare with Fig 12.)

FIG. 12.—The Horseshoe Fall from the Site of Forsyth's Hotel, 1895. (Compare with Fig. 11.)

greatest. In that region about two hundred and twenty feet of the limestone bed have been carried away, and the length of the gorge has been increased by that amount. From these data it has been computed that the cataract is making the gorge longer at the rate of between four and five feet a year, and the general fact determined by the observation of falling masses and the comparison of pictures thus receives a definite expression in the ordinary terms of time and distance.

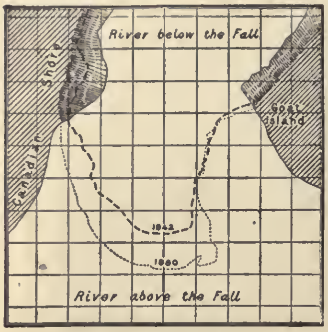


FIG. 13.—Outlines of the Crest of the Horseshoe Fall.

The vertical and horizontal lines are 200 feet apart.

The agent which has wrought such important changes during the brief period to which careful observation has been limited is manifestly able to hollow out the entire gorge if only granted enough time, and the theory which ascribes the making of the gorge to the work of the falling water is thus strongly supported.

MODE OF RECESSION.—Before passing to other facts bearing on this point, it is well to call attention to certain peculiarities of the process whereby it differs from the normal process of cataract erosion. Pure water has little power to erode solid rock. It can pick up loose particles or roll them along; but firm, coherent rock cannot be broken by so soft a tool. Rock is, indeed, worn away by rivers, and the erosion accomplished in this way is enormous; but the water does it indirectly by carrying along rock fragments which rub and pound the solid rock of the river bottom. The rock fragments are of the same material, generally speaking, as the solid rock, and they wear it away just as diamond dust wears the solid gem. As already pointed out, the Niagara is peculiar in that its current carries no rock fragments. The geographic work performed by the cataract is practically dependent on the tools furnished by the blocks of fallen limestone. It is therefore of prime importance to the work of the cataract that it shall be able to roll the limestone fragments about, and thus grind them against the river bed. A study of the different parts of the cataract, comparing one with another, shows that the water has this power only where its body is great; namely, in the middle part of the Horseshoe curve. Under each edge of that fall and under the Amer-

ican Fall great blocks of limestone lie as they have fallen, manifestly too large to be moved by the moderate streams that beat against them. Some of these are shown in the general view of the Horseshoe Fall (Fig. 8), and more clearly in the view of the American Fall (Fig. 9). The block at the extreme right of the American Fall is also pictured in Fig. 14. The resistance opposed by these blocks makes the rate of erosion of the American Fall comparatively slow. In fact, it is so slow that attempts to measure it have thus far been unsuccessful, because the changes which have taken place in its outline between the dates of surveys have been little greater than the inaccuracies of the surveys. Where the heaviest body of water pours down, the blocks are not merely moved, but are made to dig a deep hollow in the shale. The precise depth cannot be measured, because the motion of the water is there too violent for sounding; but a little farther down the river, where the cataract performed its work only a few centuries ago, the plummet shows a depth of nearly two hundred feet, and it is probable that the hollow directly under the Horseshoe is not shallower than that. The general fact appears to be that in the center of the main stream the water digs deeply, and the brink of the fall recedes rapidly. After the gorge has been lengthened by this process, it is somewhat widened by the falling in of its sides; and this falling in is in a measure aided by the thinner water streams near the banks, which clear away the smaller limestone fragments, though leaving the larger. After the cataract has altogether passed, the cliff is further modified by frost. The wall of shale, being wet by spray or rain, is exposed to the cold air of winter, and the water it contains is frozen. The expansion of freezing breaks the rock, either crumbling it or causing flakes to fall

Fig. 14.—The "Rock of Ages," a Fallen Block of Niagara Limestone at the Southern Edge of the American Fall.

away. In this way the shale is eaten back, and the limestone above is made to fall, until enough fallen fragments have been accumulated to protect the remainder of the shale from frost, after which time the process of change becomes exceedingly slow.

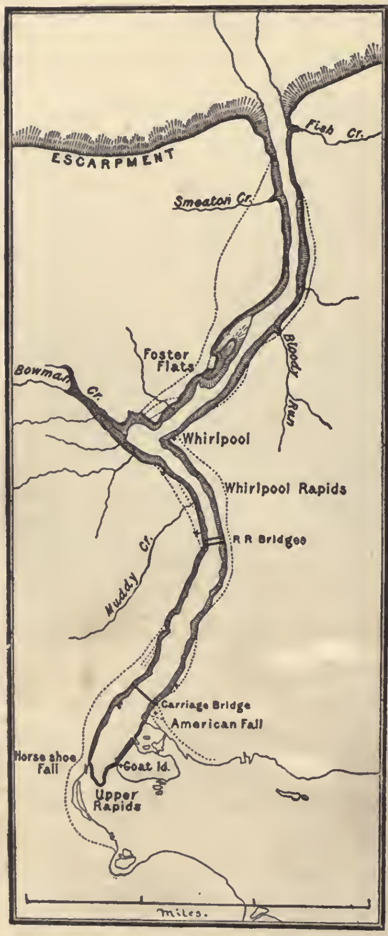


FIG. 15.—The Niagara Gorge, showing Physical Features.

Old river banks are shown by dotted lines; shell localities, by crosses.

Thus two different modes of cataract recession are illustrated by the two falls of Niagara. They resemble each other in the most essential particular,—that the soft shale beneath is worn away, and the hard limestone above falls for lack of support,—but they differ widely in other respects. In the recession of the Horseshoe Fall, the blocks of limestone are pestles or grinding tools by which the shale is beaten or scoured away. In the recession of the American Fall, the limestone blocks have no active share, but are rather obstructive. The falling water, striking them, is splashed against the cliff, and this splashing is the only force continually applied to the shale. In the spring, ice cakes are drifted from Lake Erie into the entrance of the river, and float to the falls. Borne with the water, they, too, must be dashed against the cliff of shale, and, though softer than the shale, they probably help to dislodge it. The recession in one case is far more rapid than in the other, the difference being explained primarily by the difference in the volume of the water.

OLD RIVER BANKS AND GRAVELS.—As just explained, the retreating cataract lengthens the gorge most rapidly in the middle of the stream, where the water is deepest. As the gorge is extended, the current turns toward its head from both margins,

and portions of the river bed on either side are thus gradually abandoned by the water. After these strips of river bed have become dry land, they retain certain features by which they can be recognized. Usually the whole of the drift is washed away as far as the water extended, so that the rock is bare, or nearly bare; and the edge of the undisturbed drift at the margin of this strip of bared rock has a steep slope, which so closely resembles the modern banks of the river above the cataract that the imagination readily restores the former outline of the water (see Fig. 16).

Fig. 16.—Old River Bank and River Bed, One Mile North of American Fall.

Sometimes the river, after running for a while at one level, has been drawn down to a lower level, and the change has caused a second bank to be produced, the space between the first and second banks standing as a bench of land, or terrace. At some points there are two or three such terraces. Along the greater part of the gorge these old banks can be found on both sides, and there are few spots where they do not survive on one side or the other. The farthest point to which they can be traced downstream is about half a mile from the end of the gorge, and

they thus serve to show that all the remainder of the gorge has been wrought during the life of the river; for it is evident that the river could not run on the upland while the gorge was in existence.

In a few cases, where the top of the limestone lies rather low, the old river beds are not excavated down to the rock, but their terraces are partly carved in drift. In yet other places the old river not only carried away material, but made additions, leaving a deposit of gravel and sand that had been rolled along by the current. In this gravelly deposit, shells have been found at a number of places, and they are all of such kinds as live in the quieter parts of the river at the present time.

On the chart on page 218 (Fig. 15) the most important of the old river banks are shown, and also a number of spots at which shells have been found in the river gravels.

Foster Flats.—About two miles and a half south of the escarpment the gorge assumes a peculiar phase not elsewhere seen. It is unusually wide at the top; but the river is quite narrow, and runs close under the cliff on the eastern or American side. On the Canadian side an irregular lowland lies between the cliff and the river, but this is encroached on by a quadrangular projection of the cliff. The lowland is Foster Flats; and

Fig. 17.—Bird's-eye View of Foster Flats, looking Southwest (Forests omitted).

the cliff projection, Wintergreen Flat. These and other features of the locality are portrayed in the bird's-eye view (Fig. 17), and also in the map (Fig. 18). The map represents the slopes of the land by means of contour lines, or lines of equal height, drawn at vertical intervals of twenty feet.

Wintergreen Flat is a platform of limestone a little below the general level of the plain, and separated from the plain by a steep bluff. This bluff is one of the old river banks, very similar to the one pictured in Fig. 16, and the platform is part of the river's bed. Following the direction of flow—parallel to the bank—to the point *A* (Fig. 18), the observer finds himself on the brink of a cliff over which the water evidently descended in a cataract; and before him, extending from the foot of the cliff to the point *B*, is a descending valley with the form of a river bed. From Wintergreen Flat only its general shape can be made out, as it is clothed with forest; but when one gets down to it, he finds it a northward-sloping plain, bounded by steep sides, and strewn here and there with great fallen blocks of limestone which the river current could not remove. The left

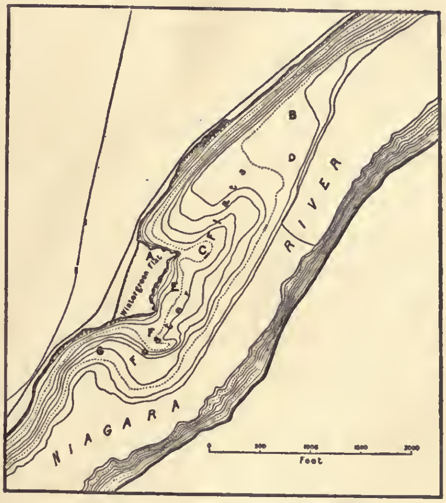


FIG. 18.—Map of Foster Flats.

bank of this channel has the ordinary profile of the wall of the gorge,—a cliff of the Niagara limestone at top and a talus slope below, covered by blocks of the same rock. The right wall is lower, rising at most but fifty feet above the channel, and gradually disappearing northward. It is merely the side of a low ridge which separates the abandoned channel from the river bed at the east. Its surface is exceedingly rugged, being covered by huge blocks of limestone, so that the ridge seemingly consists of a heap of them; but there is doubtless a nucleus of undisturbed shale, with a remnant of the Clinton ledge. Eastward from Wintergreen Flat there is a continuous descent from the limestone cliff to the river; but this is less steep than the ordinary talus slope of the gorge, and it is cumbered, like the ridge, by

blocks of limestone. There is an obscure terrace at about the level of the Clinton limestone, and there are other irregular terraces on the southward prolongation of the slope.

The history which appears to afford the best explanation of these features is as follows: When the cataract, in its recession from the escarpment, had reached the point *B*, it was a broad waterfall. Just above it, occupying the position *C — D*, was a narrow island, dividing the river as Goat Island now divides it. On reaching the island, the cataract was separated into two parts corresponding to the present Horseshoe and American falls, only at that epoch the greater body of water passed on the American side of the island, so that the American Fall retreated upstream the more rapidly. When the Canadian Fall reached the head of the island, the American had just passed it, and part of the sheet of water on Wintergreen Flat was drained eastward into the gorge opened by the American Fall. The Canadian Fall, through the loss of this water, became less active, and soon fell out of the race, leaving the cliff at *A* to record its defeat. For a time there was a cataract at *E* falling over the west wall of the gorge just as the modern American cataract falls over the east wall. The island was not broad enough to survive as a monument. After the cataracts had passed, its pedestal of shale was crumbled by the frost, and the unsupported limestone fell in ruins. As the main fall retreated still farther, the western portion of the water sheet was withdrawn from Wintergreen Flat, occupying a position at *F*, and at the same time the stream near the Canadian shore acquired greater volume, so as to recede rapidly toward *G* and thus broaden the channel. Probably at about the same time the whole amount of water in the river was increased in a manner to be considered later.

When the reader next visits Niagara, he will find himself fully repaid for his pains if he will go to this spot, and examine these features for himself. It is peculiarly impressive to stand on the silent brink of the old waterfall and look down the dry channel, and it is no less impressive to enter that channel and wander among the blocks of rock which record the limit of the torrent's power to transport. It is evident that here the cataract did not hollow out a deep pool, as under the Horseshoe Fall of to-day, but was rather comparable in its mode of action to the American Fall, though perhaps somewhat more vigorous. The slope eastward from Wintergreen Flat probably corresponds

closely with what one would find under the American Fall if the river were stopped and the pool drained.

Thus Foster and Wintergreen flats repeat the story told by the old river banks and the shell-bearing gravels. There was a time when there was no gorge, but when the river ran over the top of the plain nearly to its edge; and since that time the gorge has been gradually dug out by the power of the plunging water.

Beginning of Recession.—When the geographer notes that some natural process is producing changes in the features of the land, he naturally looks backward, if he can, to see what were the earlier features which preceded the changes in progress, and looks forward to see what will be the eventual condition if changes of the same sort are continued. The tracing of the history of change in either direction is apt to be difficult, because it is not easy to tell what allowances to make for changes of circumstance or condition. In tracing the early history of Niagara such difficulties as these arise, but there is one difficulty which is not altogether unfortunate, because it leads to the discovery that the Niagara history is definitely related to one of the most interesting events of the geographic development of the continent.

Having learned from the cataract that it is engaged in the work of gorge making, and having learned from the old river beds along the margins of the gorge and from the old cataract cliff at Foster Flats that this work of gorge making has been carried on through the whole length of the gorge, we are carried back in imagination to an epoch when the river traveled on the upper plain all the way from Lake Erie to the escarpment, and there descended. The general history is clearly traced back to that point, but there it seems to stop abruptly. We may compare the river to an artisan sawing the plateau in two. The work goes on merrily and the saw cut is still short. As geologists reckon time, it is not long since the task was begun. But Nature's artisans cannot stand idle; while they live, they must work. So, before this task was begun, either the stream had some other task or else there was no Niagara River. It seems impossible to suggest any other task, and all geographers are agreed that there was none. The river's first work was the digging of the gorge, and the date of its beginning was the date of the river's beginning.

The nature of this beginning, the series of events which led

up to it, or, in other words, the cause of the river, was long sought in vain; and an interesting chapter might be written on the fruitless search. The needed light was an understanding of the origin of the drift; and it was not till a young Swiss geologist, Louis Agassiz, brought from the Alps the idea of a drift-bearing ice field that the discovery of Niagara's pedigree became possible.

DEVELOPMENT OF THE LAURENTIAN LAKES.

The Ice Sheet.—The history of the great Canadian glacier is a large subject, to which some future monograph of this series will doubtless be devoted. Any account of it which can be given here must needs be inadequate, yet a full understanding of Niagara cannot be reached without some knowledge of the glacier. In the latest of the geologic periods the climate of North America underwent a series of remarkable changes, becoming alternately colder and warmer. While the general temperature was low, there was a large area in Canada over which the fall of snow in winter was so deep that the heat of summer did not fully melt it; so that each year a certain amount was left over, and in the course of centuries the accumulation acquired a depth of thousands of feet. By pressure, and by melting and freezing, the snow was packed, and welded into ice. When the climate again became warmer, this ice was gradually melted away; but while present it performed an important geographic work. Ice in large masses is plastic; and when the ice sheet had become thick, it did not lie inert and motionless, but spread itself outward like a mass of pitch, its edges slowly pushing away from the central tract in all directions. This motion carried the ice border into regions of warmer climate, where it was melted; and for a long period there was a slow but continuous movement from the central region of accumulation to the marginal region of waste by melting. The principal region of accumulation was north and northeast of the Great Lakes, and the flowing ice passed over the lake region, invading all our Northern States. Where the ice pressed on the ground, it enveloped bowlders, pebbles, and whatever lay loose on the surface; and as it moved forward, these were carried with it, being dragged over the solid rock, and scraping it. Thus the country was not merely swept, but scratched and plowed, with the result that its surface was worn down. The amount of wear was not

everywhere the same, but varied from place to place, and many basins were hollowed out. When the general climate became gradually warmer, the waste of ice near its margin exceeded the supply, and the extent of the sheet was diminished. When the ice was gone, the stones and earth it had picked up and ground up remained on the land, but in new positions. They were spread and heaped irregularly over the surface, constituting the mantle of *drift* to which reference has already been made. Thus by the double process of hollowing and heaping, the face of the land was remodeled; so that when the rain once more fell on it, and was gathered in streams, the old water ways were lost, and new ones had to be found.

This remodeling gave to the Laurentian system of water ways its abnormal character, supplying it with abundant lakes and waterfalls. Not only were the Great Lakes created, but a multitude of minor lakes, lakelets, ponds, and marshes. If the reader will study some good map of the United States or of North America, he will see that this lake district includes New England also, and by tracing its extent in other directions he can get a fair idea of the magnitude of the ice sheet.

The lakes have had a marked influence on the history and industries of mankind. Still water makes an easy roadway, and the chain of Great Lakes not only guided exploration and early settlement, but has determined the chief routes of commerce ever since. The most easterly of the ice-made basins, instead of holding lakes, receive arms of the sea, giving to New York and New England some of the best harbors in the world. Each cataract is a water power, and the lakes and ponds upstream are natural storage reservoirs, holding back floods, and doling the water out in time of drought. So Chicago and New York City are the centers of trade, and New England is a land of humming spindles and lathes, because of an invasion long ago by Canadian ice.

The district of the Niagara lay far within the extreme limit of the ice, and the drift there lying on the rocks is part of the great ice-spread mantle. Wherever that drift is freshly removed, whether by the natural excavation of streams or the artificial excavation of quarrymen and builders, the rock beneath is found to be polished, and covered by parallel scratches, the result of rubbing by the ice and its gritty load. These scratches show that in this particular district the ice moved in a direction about

30° west of south. They can be seen on the western brink of the gorge four hundred yards below the railroad suspension bridge, in the beds of several creeks near the Whirlpool, and at various quarries above the escarpment. The best opportunity to study them is at a group of quarries near the brink of the escarpment, about two miles west of the river.

Ice-dammed Lakes.—During the period of final melting of the ice sheet, when its southern margin was gradually retreating across the region of the Great Lakes, a number of temporary lakes of peculiar character were formed. In the accompanying sketch map of the Great Lake region (Fig. 19) the broken line marks the position of the southern rim of the St. Lawrence basin. It is the watershed between the district draining to the St. Lawrence and the contiguous districts draining to the Mississippi, Ohio, Susquehanna, and Hudson. When the ice sheet was greatest, its southern margin lay south of this watershed. The rain which fell on the ice, uniting with the water made by melting ice, ran from the ice field on to the land, and flowed away with the rivers of the land. Afterward, when the extent of the ice had been somewhat reduced, its margin lay partly beyond and partly within the basin of the lakes; but the water from it could not flow down the St. Lawrence, because that valley was still occupied by the ice. It therefore gathered between the ice front and the watershed in a series of lakes, each of which found outlet southward across some low point in the watershed. To see this clearly may require some effort of the imagination. The reader should bear in mind that the watershed is not a simple ridge, but a rolling upland of varying height, with here and there a low pass. The St. Lawrence basin is not simple and regular in form, but is made up of many smaller basins separated by minor uplands or watersheds. Some of these watersheds are shown on the map. When the ice occupied part of minor basins, it acted as a dam, holding the water back, and making

Fig. 19.—The Great Lakes and their Drainage Districts.

The watersheds bounding the drainage districts are represented by dotted and broken lines.

it fill the basin until it could flow in some other direction. As the position of the ice front changed, these lakes were changed, being made to unite or separate, and often to abandon one channel or outlet when another was opened at a lower level. Sometimes there were chains of lakes along the ice margin, one lake draining to another across a minor watershed, and the lowest discharging across the main watershed.

Wherever water ran from a lake, it modified the surface. The loose drift was easily moved by the current, and each stream quickly hollowed out for itself a channel,—a trough-like passage with flattish bottom and steep sides. When the lakes afterward disappeared, the channels lost their streams, but their forms remained. They are still to be seen in a hundred passes among the hills of the Northern States. The larger and longer-lived of the lakes carved by their waves a still more conspicuous record. In ways explained by Professor Shaler in the fifth monograph of this series, the waves set in motion by storms cut out strands and cliffs from the drift and built up barrier beaches, so that after the lake waters had departed there were terraces and ridges on the hillsides to show where the shores had been. Many of the old channels have been found, some of the old shore lines have been traced out and marked on maps, and by such investigation the history of geographic changes in the Great Lake region is gradually being learned.

At one stage of that history there was a long lake occupying the western part of the Ontario basin, much of the Erie, part of the Huron, and probably part of the Michigan. Its outflow crossed the main watershed at Chicago (*C*, Fig. 19), and its eastern extremity was near Batavia (*B*) in western New York. The ice mass filled the greater part of the Ontario basin, and kept the water from escaping eastward. When it melted from that region, the water shifted its outlet from Chicago to a low pass at Rome (*R*), where it discharged to the Mohawk valley. This change lowered the lake surface several hundred feet, and, by uncovering watersheds that had before been submerged, separated the Huron, Erie, and Ontario basins, and three lakes took the place of the single long lake. In the Huron basin was a lake half walled by ice; in the Erie basin, Lake Erie; and in the Ontario basin, Lake Iroquois, an ice-dammed lake with its outlet at Rome.

The draining away of so large a body of water occupied some

time, so that the lake level was gradually lowered. When it reached the pass between the Erie and Ontario basins at Buffalo, and Lakes Erie and Iroquois were thereby parted, the Erie level could fall no lower, but the Iroquois continued downward. As soon as there was a difference of level, a stream began to flow from Lake Erie, and that stream was the infant Niagara, newly born. It was a short stream, because the edge of the Iroquois water was close to Buffalo; but it grew longer day by day, as fast as the Iroquois edge receded. It had no channel until it made one, but its growing end, in following the retreating lake, selected at each instant the direction of steepest slope; and as the slopes had been formed by the glacier, it may be said that the glacier predetermined the course of the river.

During some centuries or millenniums of its early life the river was shorter than now, because the Iroquois Lake flooded more land than the Ontario, and kept the river nearer the escarpment; but in course of time the ice dam disappeared, the lake outlet was removed from Rome to the Thousand Islands, part of the lake bottom was laid bare by the retiring water, and the river stretched itself over the broadened plain. It grew, in fact, to be a few miles longer than now, and there were other changes in length; but the entire story is too long and intricate for these pages.

The Canting of Basins.—The geographers who have mapped the glacial lakes by tracing their shore lines have also measured the heights of these lines at many points. From these measurements they have found that the lines are not level. The surface of each ice-dammed lake was, of course, level, and its waves, beating on the shores, carved beaches and strands all at the same level. But these abandoned strands, preserved as terraces on the basin slopes, are not level now; and it is therefore inferred that the earth itself, the rocky foundation on which the terraces rest, has changed its form. The idea of earth movements, the slow rising of some districts and the sinking of others, is not new; but, until these old shore lines were studied, it was not known that such changes had recently affected the Lake region.

The departure of the old shore lines from horizontality is of a systematic character. They all rise toward the north and east, and fall toward the south and west. The amount of this tilting or inclination is not the same everywhere, nor is it everywhere in precisely the same direction; but the general fact plainly

appears, that the northeastern portion of the Great Lake district has been raised or the southwestern portion has been lowered, or both, several hundred feet since the epoch of these ice-dammed lakes, i.e., since the time when the Canadian ice sheet was slowly melting away. The effect of this change was to tip or cant each lake basin, and the effect of the canting was similar to the effect of canting a hand basin containing water. In the hand basin the water rises on the side toward which the basin is tipped, and falls away on the opposite side. In the lake basin there was a constant supply of water from rain and streams, so that it was always filled up to the level of the lowest point of its rim, and the surplus of water flowed away at that point; so, when it was canted, the changes in the extent of the lake were partly controlled by the outflow. If the outlet was on the northeastern side of the basin, the southwesterly canting would make the water rise along its southwestern shore, the submerged area being thereby enlarged. If the outlet was toward the southwest, then the canting would draw the water away from the northeastern slopes, and diminish the submerged area. If the lowest point of the rim was originally on the northeast side, the canting might lift this part of the rim so high that some point on the southwest side would become lowest, and the point of outlet might thus be changed from north or east to south or west. The evidence of the old shores and channels shows that all these possible changes have actually occurred in the lake basins, and that some of them were related in an important way to the history of the Niagara River.

The gradual canting affected the size of Lake Erie, Lake Ontario, and the temporary Lake Iroquois, making each grow toward the southwest. When Lake Erie was born, its length could not have been more than half as great as now, and its area was much smaller. The original Lake Huron may have had about the same size as the present lake, but its form and position were different. Less land was covered at the south and west, more land at the north and east, and the outlet was at North Bay (*N*, Fig. 19). By the tipping of the basin the lake was made gradually to expand toward the west and south till at last the water reached the pass at the head of the St. Clair River. Soon afterward the water ceased flowing through the North Bay outlet. The water then gradually withdrew from the northeastern region till finally the shores assumed their present position.

At an earlier stage, while the North Bay district was blocked by the ice sheet, it is probable that the basin had an outlet near Lake Simcoe (*S*), but the evidence of this is less complete. If the Huron water crossed the basin's rim at that point, it followed the Trent valley to Lake Iroquois or Lake Ontario; when it crossed the rim at North Bay, it followed the Ottawa valley to the St. Lawrence; and in each case it reached the ocean without passing through Lake Erie and the Niagara River. Thus there was a time when the Niagara River received no water from the Huron, Michigan, or Superior basins, but from the Erie basin alone. It was then a comparatively small stream, for the Erie basin is only one eighth of the whole district now tributary to the river; and the cataract more nearly resembled the American Fall than the Horseshoe.

THE WHIRLPOOL.

The Whirlpool is a peculiar point in the course of the river. Not only does the channel there make an abrupt turn to the right, but with equal abruptness it is enlarged and again contracted. The pool is a deep oval basin, communicating through narrow gateways with the gorge above and the gorge below. The torrent, rushing with the speed of an ocean greyhound from the steep, shallow passage known as the Whirlpool Rapids, enters the pool and courses over its surface till its headway is checked. The initial impulse prevents it from turning at once toward the channel of exit, and the current circles to the left instead of the right, following the curved margin of the pool, and finally descending under the entering stream so as to rise beyond it at the outlet. Thus the water describes a complete loop, a peculiarity of current quite as remarkable and rare as the feats of railway engineering which bear that name. In the chart of the Whirlpool (Fig. 20) the surface currents are indicated by arrows; and some idea of the appearance of the currents may be obtained from the view in Fig. 7, where the swift incoming current crosses the foreground from right to left, and the exit current occupies the middle of the picture. In the smoother tract between these two visible currents the water rises after passing under the nearer. These currents can be watched from any of the surrounding cliffs, and there is a fascination about them akin to that of the cataract itself and the Whirlpool Rapids.

The gorge above, the gorge below, and two sides of the Whirlpool are walled by rock; but the remaining side, that opposite to the incoming stream, shows no rock in its wall (Figs. 20 and 21). On the north side, the edge of the Niagara limestone can be traced to *A* (Fig. 20) with all its usual characters, but there it disappears beneath the drift. The Clinton limestone disappears in a similar way just below it, and the quartzose sandstone, which there skirts the margin of the water, is a little more quickly covered, being last seen at *B*. On the south bank the Niagara limestone can be traced farther. Its edge is visible almost continuously to *E*, and is laid bare in the bed of a small creek at *F*. The Clinton bed is similarly traceable, with slight interruption, to *D*; and the quartzose sandstone passes under the drift at *C*. Where each rock ledge is last seen it points toward the northwest, and betrays no tendency to curve around and join its fellow in the opposite wall. In the intervening space the side of the gorge seems to be composed entirely of drift. Sand and clay, pebbles and bowlders, make up the slope; and a beach of bowlders margins the water from *B* to *C*. It is inferred from this arrangement of rock and drift that there was a deep hollow in the plain before the drift was spread by the ice, the drift being deposited in it and over it until it was filled and covered. The parallel directions of the rock ledges suggest that the hollow was part of a stream channel running northwestward; and this interpretation is borne out not only by certain topographic features two or three miles away, but by a study of the bed and banks of Bowman Creek (Fig. 15). That stream, which rises two miles away, has carved a ravine where it approaches the Whirlpool. The northeast bank of the ravine (Fig. 20) seems to be composed entirely of drift; but the opposite bank, though chiefly of drift, lays bare the rock at a number of places, revealing a sloping wall descending toward the northeast. The bed of the stream in general shows nothing but drift; but there is one place where the creek swerves a little to the southward, and

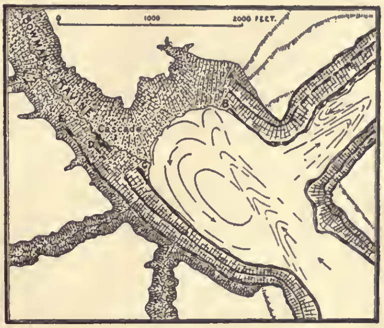


FIG. 20.—The Whirlpool.

Rock is indicated by crosshatching; drift, by dots. Arrows indicate the direction of current.

for a few rods presses against the rock slope; and it has there made a small cut into the rock, cascading at one point over a sandy ledge that is harder than the associated shale.

With the aid of this information, it is easy to understand the peculiar features of the Whirlpool. The Niagara River did not seek this old channel and thus find an easy way northward, but ran upon it accidentally at one point. Its course on the plain was determined for it by the slopes of the drift, and the arrangement of these slopes happened to guide the water across the buried channel at the Whirlpool. In making the gorge from the Whirlpool to the escarpment, and also in making the upper part of the gorge, the river found hard rock to be removed; and it worked as a quarryman, digging down below in the softer rocks with such tools as it had to use, and thus undermining the limestone cap. At the Whirlpool there was no need to quarry, because there was no limestone cap; and, to carry out the homely figure, the river merely dug in a gravel pit, shoveling the loose drift quickly away. This work of excavation did not cease when a channel of the usual width had been opened, because the angle in the course of the river set the current strongly against the bank of drift, and caused it to clear out a basin in the old channel. Had the drift been wholly, as it is partly, of sand, still more of it would have been carried out; but it included large bowlders, and these were sorted out and accumulated until they made a sloping wall or sheathing, which covers all that part of the sand below the level of the pool, and resists further encroachment by the water. So the peculiar form of the river at this place was caused by the old channel with its filling of loose sand and gravel. The looped current evidently depends on the peculiar shape of the channel. The water enters the pool with such impetus that it is carried past the outlet, and the return current follows the bottom of the pool because that route is the easiest.

TIME.

Just under the escarpment where it is divided by the river stand two villages,—the American village of Lewiston, the Canadian village of Queenston. Lewiston is built partly on an old beach of Lake Iroquois, and near its steamboat wharf is a gravel pit where one can see the pebbles that were worn round by rolling up and down the old strand. That part of the escarp-

ment which overlooks Lewiston is somewhat terraced, or divided into steps, and was called "The Three Mountains" a century ago, when loads that had been brought by boat to the landing (Lewiston) were toilsomely carried up the steep ascent on their way to other boats plying on the upper Niagara.

The escarpment above Queenston is called Queenston Heights; and from its crest rises Brock's monument, a slender shaft commemorative of a battle between British and American soldiers. Within this shaft is a spiral staircase, and from a little chamber near the top one can look through portholes far away in all directions. Eastward and westward runs the escarpment, and the eye follows it for many miles. Southward stretches the upper plain, diversified by low, rolling hills, and divided in the foreground by the gorge. In the still air a cloud of spray hovers over the cataract, and a cloud of smoke at the horizon tells of Buffalo. Northward lies blue Ontario, and straight to its shore flows the deep-channeled, majestic Niagara, dividing the smooth green lowland into parts even more closely kin than the brother nations by which they are tilled. Beyond the water, and forty miles away, gleams Scarboro Cliff, where the lake waves are undermining a hill of drift; and twenty or thirty miles farther the imagination may supply—what the earth's roundness conceals from the eye—a higher upland that bounds the Ontario basin.

The Brock monument, the Niagara gorge, and the Ontario basin are three products of human or of natural work, so related to time that their magnitudes help the mind in grasping the time factor in Niagara history. The monument, measured in diameter by feet and in height by scores of feet, stands for the epoch of the white man in America. The gorge, measured in width by hundreds of yards and in length by miles, stands for the epoch since the ice age. The basin, measured in width by scores of miles and in length by hundreds of miles, stands for a period before the ice, when the uplands and lowlands of the region were carved from a still greater upland. The monument is half a century old; the gorge was begun some tens or hundreds, or possibly thousands, of centuries ago; and the hollowing of the basin consumed a time so far beyond our comprehension that we can only say it is related to the gorge epoch in some such way as the gorge epoch is related to the monument's half century.

The glacier made changes in the Ontario basin, but they were

small in comparison with its original size, and the basin is chiefly the work of other agents. Before the glacial age it was a river valley, and we may obtain some idea of its origin by thinking of the Niagara gorge as the beginning of a river valley, and trying to imagine its mode of growing broader. It has already been explained (p. 218) that the gorge walls fall back a little after the cataract has hewn them out, but seem to come to rest as soon as all the shale is covered by talus. So nearly do they approach rest that their profile is as steep near the mouth of the gorge as it is one mile below the cataract; but, in fact, they are not unchanging. Water trickling over the limestone cliff dissolves a minute quantity of the rock. This makes it porous, and lichens take root. Lichens and other plants add something to the water that increases its solvent power. The fragments of the talus are eaten faster because they expose more surface. Each winter the frost disturbs some of the stones of the talus, so that they slowly move down the slope; and wherever the shale is laid bare, frost and rain attack it again. Thus, with almost infinite slowness,—so slowly that the entire age of the gorge is too short a unit for its measurement,—the walls of the gorge are retreating from the river. At the same time every creek that falls into the gorge is making a narrow side gorge. The strongest of them has worked back only a few hundred feet (Fig. 15); but in time they will trench the plain in many directions, and each trench will open two walls to the attack of the elements. Space forbids that we trace the process further; but enough has been said to show that valleys are made far more slowly than gorges, and that the ancient shaping of the land into valley and upland was a far greater task than the comparatively modern digging of the gorge.

The middle term of our time scale, the age of the gorge, has excited great interest, because the visible work of the river and the visible dimensions of the gorge seem to afford a means of measuring in years one of the periods of which geologic time is composed. To measure the age of the river is to determine the antiquity of the close of the ice age. The principal data for the measurement are as follows: (1) The gorge now grows longer at the rate of four or five feet a year, and its total length is six or seven miles. (2) At the Whirlpool the rate of gorge making was relatively very fast, because only loose material had to be removed. Whether the old channel ended at the Whirlpool, or

extended for some distance southward on the line of the river, is a matter of doubt. (3) Part of the time the volume of the river was so much less that the rate of recession was more like that of the American Fall than that of the Horseshoe. Some suggestions as to the comparative extent of slow work and fast work are to be obtained from the profile of the bottom of the gorge. While the volume of the river was large, we may suppose that it dug deeply, just as it now digs under the Horseshoe Fall (see p. 216); while the volume was small, we may suppose that a deep pool

FIG. 21.—Longitudinal Section of the Niagara Gorge, with Diagram of the Western Wall.

The base line is at sea level. It is divided into miles. Water, black; drift, dotted; Niagara limestone in block pattern; shales, broken lines; F, falls; R, railway bridges; W, whirlpool; Foster, Foster Flats; E, escarpment.

was not made. Fig. 21 exhibits the approximate depth of the water channel through the length of the gorge; and by examining it the reader will see that the depth is great near the mouth of the gorge, again from the head of Foster Flats to the Whirlpool, and then from the bridges to the Horseshoe Fall. It is small, indicating slow recession, in the neighborhood of Foster Flats, and also between the Whirlpool and the railroad bridges. The problem is complicated by other factors, but they are probably less important than those stated.

Before the modern rate of recession had been determined, there were many estimates of the age of the river; but their basis of fact was so slender that they were hardly more than guesses. The first estimate with a better foundation was made by Dr. Julius Pohlman, who took account of the measured rate of recession and the influence of the old channel at the Whirlpool; he thought the river not older than 3,500 years. Dr. J. W. Spencer, adding to these factors the variations in the river's volume, computes the river's age as 32,000 years. Mr. Warren Upham, having the same facts before him, thinks 7,000 years a more reasonable estimate. And Mr. F. B. Taylor, while regarding the data as altogether insufficient for the solution of the problem, is of opinion that Mr. Upham's estimate should be multiplied by a number consisting of tens rather than units. Thus estimates founded on substantially the same facts range

from thousands of years to hundreds of thousands of years. For myself, I am disposed to agree with Mr. Taylor, that no estimate yet made has great value, and the best result obtainable may perhaps be only a rough approximation.

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MOUNT SHASTA, A TYPICAL VOLCANO.

By J. S. Diller.

THE VOLCANIC PROCESS.

Seeds are wafted by the wind to fertile soils, where they germinate and take root, and in time the mighty pine becomes the pride of the forest; but in a few centuries it grows old, declines, is blown over by the winter storms, decays, and returns to the soil whence it came. Animals, little at birth, grow to full stature and maturity, and in old age decline and pass away.

As with living things, so also with the glades and the hills, the valleys and the mountains. All are ever changing in course either of construction or of destruction, or of both. Each has its history more or less complete, embracing a beginning stage, a stage of maturity, and a stage of decadence.

Mount Shasta, a typical large volcano, is beyond the prime of its life. It is in the decline of its maturity. It has passed from a stage of vigorous growth into one of decadence, and is just beginning to show clearly the ravages of time. In order to prepare the way for a clearer understanding of the large volcano, it will be well to review briefly the volcanic process.

There are many forces active in changing the features of the earth's surface. As explained in the first monograph, three ways or processes in which these forces operate may be distinguished. They are *vulcanism*, *diastrophism*, and *gradation.*

Vulcanism (Monograph No. 1, p. 24) modifies the surface by the transfer of material, generally in a molten condition, outward from the earth's interior. In order to understand this transfer it is necessary to consider the conditions within the earth.

Internal Heat.— In a boring made near Wheeling, W. Va., the temperature at various depths was observed as follows: at 1,350 feet, 68.75° F.; 2,125 feet, 76.25°; 2,990 feet, 86.60°; 3,482

feet, 93.60°; 3,980 feet, 101.75°; 4,462 feet, 110.15°. The temperature thus increased downward at the rate of about 1 degree for every 75 feet. Deep borings, wells, and mines at many points upon the earth's surface show that everywhere the temperature increases downward in the earth. Although the rate varies with the place, the average increase is about 1 degree for every 45 to 75 feet. The rate of increase indicates that at a depth of 50 miles beneath the surface the temperature is higher than that required to melt iron under ordinary conditions. The source of this internal heat, whether a residue from the original incandescent earth, or due to chemical action, or produced by the mechanical crushing of rocks, we need not stop to inquire.

FIG. 1.—Geyser in Action.

WATER.—Rain falls on the mountain slopes. Some of it gathers into rills, runs into brooks, creeks, and rivers, and finally finds its way back into the sea whence it came. Another portion enters the soil, and under the influence of gravity passes through the pores, cracks, and fissures of the rocks to various depths within the earth. On the lower slopes of the mountains, and in the valleys, much of the water which entered above reappears in the form of springs, most of which are cool and refreshing. In some cases, however, the water penetrates so far into the earth before reappearing in springs that it is warmed by the internal heat. Thus warm springs, hot springs, and boiling springs are produced. In those boiling springs in which the outlet is large enough to allow the heat to escape, the movements of the water are comparatively

uniform; but in certain cases the outlet is narrow in proportion to the length of the more or less vertical tube in the ground, and there is not sufficient opportunity for escape. The heat increases until the expansive force of the highly heated water and steam is sufficient to produce an explosion. The overlying water and steam are thrown high into the air (Fig. 1) by the *eruption*. Such springs are *geysers*, and steam is the motive power in their *eruption*.

The waters of hot springs may contain in solution carbonate of lime, silica, and other substances, which are deposited about the springs, making a mound. The one from which the geyser, as shown in Fig. 1, issues is composed of silica. Although such mounds rarely attain a height of over 20 feet, they are of sufficient physiographic importance to warrant mention here. As a class, they are among the smallest topographic eminences which are products of a process essentially volcanic in its nature.

Next more important than eruptions of water in geysers are those of mud. A notable one occurred in 1888 at Bandai-san, in Japan. Large quantities of mud, saturated with steam or highly heated water under pressure, were developed a short distance beneath the surface. A great explosion occurred, removing the whole side of the mountain. A vast quantity of steam escaped, and streams of mud flowed down the valley, damming water courses to form lakes, and destroying a number of villages.

In true volcanic action the material transferred from the interior of the earth to the surface is neither simple water, as in the geyser, nor mud, as in the semivolcanic eruption at Bandai-san, but melted rock. It comes from greater depths than either of the others, where the temperature is higher, and the rocks either in a molten condition or so hot that when the pressure upon them is relieved they fuse and become eruptible.

In the geyser and eruptions of mud the material is impelled to the surface by steam. So also the molten rock material, or *magma*, within the earth is forced along lines of least resistance toward the surface by the absorbed waters and gases it contains. Other agents may, indeed, be the principal ones in causing the upwelling of the magma from within the earth; but to its absorbed gases are due many of the conspicuous phenomena attending the delivery of the material at the surface, where it solidifies, and becomes *lava*. The large quantities of steam given

off by volcanoes in eruption are illustrated in Fig. 2 by the clouds of vapor rising from the outflow of lava of Vesuvius, in April, 1872. The whole mountain is involved in steam, rising from the molten rock which courses down its slopes.

FIG. 2.—Mount Vesuvius in Eruption, April, 1872.

ERUPTIONS INTERMITTENT.—In the upbuilding of a great volcano like Mount Vesuvius the overflows are intermittent. Eruptions which transfer molten matter from the interior to the surface of the mountain to build it higher are not continuous. The brief epochs of activity are ordinarily separated by long periods of quiescence. For centuries before the beginning of the Christian era Vesuvius was without eruption; but in the year 79 it suddenly burst into vigorous action, and the cities of Pompeii, Herculaneum, and Stabiæ, on its slopes, were overwhelmed and destroyed by the extruded material. Since then it has been in eruption many times, but the periods occupied by the extrusion of the molten matter have been very short as compared with the long intervals of repose.

FORMS OF ERUPTION.—Eruptions are of two forms,—*explosive* and *effusive*. In the first form the material is blown to fragments and violently hurled into the air. In the second the

magma wells up within the volcanic vent, and flows out over the surface in streams, forming *coulees.* These different forms of eruption are rarely distinct. Ordinarily they occur together in the same outburst, and the mountain to which they give rise has a complicated structure.

The magma, full of absorbed gases, water, or steam, distributed throughout its mass, or perhaps most abundant in the upper portion, impelled by forces not yet fully understood, rises toward the surface. When it gets near the surface, and the pressure is relieved, the occluded gases expand, often with explosive effect, and tear the viscous molten material into fine particles, which are hurled high into the air, to be spread far and wide over the land by the winds. During the great eruption of Krakatoa in August, 1883, volcanic dust was thrown to the height of over 17 miles, and the surrounding country for many miles was covered with a sheet of volcanic sand and dust.

In many cases the ejected fragments are coarser than dust, ranging in size from sand through lapilli, various forms of cinders and bombs, to blocks of lava many tons in weight. They fall about the vent from which the material is ejected, and, piling up, form a *cinder cone.* Explosive eruptions usually accompany the extrusion of viscous lava. Cinder cones generally have steep slopes, and funnel-shaped craters in their summits. They are abundant along the Cascade Range in the western portions of the great volcanic fields of California, Oregon, Washington, Idaho, and Montana.

Magmas containing a small amount of absorbed gases and vapors, or having such a high degree of liquidity as to allow the gases easily to escape, are not extruded by explosive eruptions, but are quietly poured out, forming in each case a *lava cone* around the orifice. Liquid magmas make lava cones with gentle slopes. Cones made from viscous magmas have steep slopes. By the accumulated outflows of liquid magmas for many centuries, high mountains are built up. Mauna Loa, on the Island of Hawaii, is an example of such a mountain. Its slopes are gentle, with a base at sea level 70 miles in width, and it rises to a height of about 14,000 feet above the sea. The amount of material poured out at any one time may be large or small. The activity is always intermittent, with relatively long periods of quiet separating short intervals of eruption.

As lava cones and cinder cones are built up higher and

higher by successive eruptions, the passageway or chimney through which the material comes up from the earth's interior is lengthened, and the magma rises within the chimney. The hydrostatic pressure of the column increases as it rises, until it becomes sufficient to burst open the side of the cone, and the lava flows out on the lower slopes.

Volcanoes are cinder cones, lava cones, or cones composed of both cinders and coulees. They are conical mountains made up wholly of volcanic material piled up around the vent from which it issued. Cinder cones and lava cones are common, but they are usually less imposing than the volcanoes made up of both cinders and coulees, such as result from explosive and effusive eruptions combined. From what is known of the distribution of volcanic material, it is probable that much more of it has reached the surface by effusive than by explosive eruptions.

MOUNT SHASTA.

Location.—Mount Shasta is in the middle portion of northern California, near the head waters of Sacramento River, and belongs to the Cascade Range of mountains. It immediately adjoins the Klamath Mountains of the Coast Range, and stands in line with the axis of the Sierra Nevada. In simple grandeur it rises high above its rugged neighbors as a mighty monarch among giants. The great altitude of its snow-capped summit makes it a conspicuous landmark over a large area, and has guided many a pioneer on his way to the Pacific coast. Mount Whitney rises higher above the sea than Mount Shasta; but as Mount Whitney is located among rival peaks, on an extensive elevated platform, its individual supremacy is not conspicuous. On the other hand, Mount Shasta stands alone at the head of Shasta Valley, and, although encompassed by high ridges and peaks, it still presents an imposing individuality. The traveler in that region, when he obtains a general view, need not ask which is Shasta. The mountains in its neighborhood, though reaching over 2,500 feet higher than any of the Appalachians, only serve to magnify the grandeur of Shasta, as its massive cone towers a mile above them all.

Shape and Size.—Mount Shasta seen from the east, as shown in Fig. 3, is a simple cone. So far at least as shape is concerned, it is a typical example of a large volcano, made up

of cinders and coulees which accumulated about the volcanic chimney from which they issued. No other type of mountain attains such a beautiful, graceful, yet simple and extensive stretch of slope rising into the sky. The point of view in Fig. 3 is over a mile above the sea. The summit, in its summer garb, rises 8,450 feet above us, and attains an altitude of 14,350 feet. The upper 3,000 feet of the mountain, where cliffs are most abundant,

FIG. 3.—Mount Shasta from the East.

has slopes averaging nearly 35 degrees. Farther down, the slopes gradually decrease in angle of inclination to 20 degrees, 15 degrees, and 10 degrees; and finally, about the base of the mountain, the long, gentle slope deviates but 5 degrees from a level plain. From the summit of Mount Shasta toward all points seen in the view, its flanks increase in length as they decrease in angle of inclination. The slope of the mountain as a whole is a curve concave upward, with the greatest curvature near the top.

The base of the mountain is 17 miles in diameter, and its height above the base is over 2 miles. Its volume is in the neighborhood of 84 cubic miles.

COMPOSITION AND STRUCTURE.—The form of Mount Shasta is that of a typical volcano, and we might regard the form alone as

sufficient evidence to prove the volcanic origin of the mountain. There are other facts which lead to the same conclusion.

Volcanoes are composed of rocks which result from the cooling and solidification of molten material erupted from the interior of the earth. If the material cools slowly, crystals develop; and the amount of matter crystallized is proportional to the length of time the slow cooling continues. In some cases the process is continued long enough for the whole mass to become crystallized. Generally, however, a portion of the material in lavas is not crystallized; i.e., it remains amorphous, and sometimes even glassy, because of the sudden chill terminating the gradual cooling before crystallization is complete. The structure of lavas (made up, as they are, of either crystals or amorphous material, or both) is peculiar, and affords a means of distinguishing volcanic rocks from rocks which originate in other ways.

The rocks of Mount Shasta usually contain some well-developed crystals, but a large portion of the mass is amorphous. In all cases, however, their structure is that which is peculiar to lavas, and there can be no doubt as to the origin of the rocks.

FIG. 4.—Mount Shasta from the North.

The volcanic origin of Mount Shasta is indicated not only by its form and composition, but also by its structure. It is made up of irregular layers of lava, alternating here and there with others of fragmental volcanic material. The layers overlap one another somewhat like the shingles of a conical roof, and produce the structure which is characteristic of volcanoes.

Constructional Features.—From the east, as seen in Fig. 3, Mount Shasta appears to be a single cone, as if all the lavas of which it is composed had escaped from one vent. Seen from the north, as illustrated in Fig. 4, its double structure appears. There were two important vents about a mile and a half apart. The principal summit is on the left. That on the right is Shastina, whose altitude is about 2,000 feet lower than the other. Its truncated form suggests a crater in the summit; and this suggestion is verified by ascent, as shown in the map (p. 246). The crater-like rim is well preserved, except on the west, where it is broken away. On the slopes, especially toward the base, are a number of smaller cones. Some are of cinders, and others of lava, but the most common form of addition in building up Mount Shasta was coulees without cones.

Coulees.—On the northwestern slope, at an altitude of from 5,000 to 6,000 feet, is Lava Park. Judging from the freshness of the lava, it is the youngest coulee of the mountain. The slope at that point is comparatively gentle, so that the lava spread broadly, and the coulee is nearly as wide as long. The greater portion of the park is without vegetation. It is an extremely rough pile of rocks, covering an area of about two square miles, on which there is so little soil that arboreal vegetation has not yet obtained a hold. It ends on all sides abruptly, like a terrace. The magma was viscous at the time of its extrusion, and broke into sharp, angular blocks as it was pushed along over the surface. The general character of this coulee is much like that shown in Fig. 5, which represents a coulee on the little Snag Lake cinder cone, 58 miles southeast of Mount Shasta. This form of coulee is exceptional on the slopes of Mount Shasta.

A well-marked coulee occurs on the western slope. It burst forth at an elevation of 5,000 feet, and flowed northwestward in a rather narrow stream for several miles. The surface of this flow is like that of Lava Park.

A comparatively recent coulee appears on the southwestern slope of the mountain. The trail up the mountain follows this

Surveyed by U.S. Geological Survey, 1884. Eugene Ricksecker Topographer

New roads about Sissons furnished by George H. Peck

MAP OF MOUNT SHASTA.

coulee for several miles; and the rough, hackly, steam-torn surface of the lava is well exposed. It is timbered like the adjoining slopes, showing that the flow is older than either of the other two mentioned. Its surface has not been scored by the ancient

FIG. 5.—The Surface of a Coulee at Snag Lake Cinder Cone.

glaciers which once covered a large part, if not the whole, of the southwestern slope of the mountain. It is evident that its extrusion occurred since the period of greatest glacial extension, the glacial period.

On the northeastern slope of the mountain, at an elevation of

nearly 10,000 feet, several well-marked coulees have their source. Their tabular form may be distinguished in Fig. 3 between the snow and the forest. The longest forms the flat divide between the upper portions of Brewer and Inconstance creeks, and courses down the mountain slope for over four miles. Below, it widens out and rises higher and higher above the adjacent surface. The lower end is abrupt, and forms a prominent cliff. The top is flat from side to side, but the edges of the flow are steep. At the head of Brewer Creek is a short tabular coulee terminating below in a cliff, but the cliff is not so high as that which terminates the longer coulee. In general, the newer flows, forming the upper portion of the mountain, are smaller than the older ones over which they were poured out. All end below in cliffs; so that, as one ascends the mountain, here and there he mounts as if on giant stairs, with long inclined steps (or treads) and steep risers, over the ends of the successively shorter lava flows.

The later flows that burst from the upper portion of the mountain were more viscous, and generally less copious, than those which issued from the base. The former built up the steep slopes, while the latter spread out the gentler slopes below, and occasionally formed extensive flats, as shown in the foreground of Fig. 4. At the southeast base of the mountain, Elk Flats is underlined by a basaltic lava, which at the time of its extrusion was much more liquid than most of the lavas of Mount Shasta. It doubtless contained large quantities of steam at the time of its eruption, for the lava is full of small cavities (bubbles), due to the expansion of the gases it originally contained.

The longest coulee from Mount Shasta is one which issued from the southern slope of the mountain at an elevation of about 5,500 feet, a little more than a mile southwest of the Wagon Camp. The plenteous flow of lava spread from a cone on the crest of the ridge, sending one arm of the broad coulee toward Panther Creek, and another toward the Sacramento. It completely surrounded Bear Butte, and forced Panther Creek eastward. It flowed between the hills of metamorphic rocks along Soda and Squaw creeks. This branch of the great coulee terminated within a dozen miles of its source. The other arm of the flow entered the canyon of Sacramento River, which it followed for nearly 50 miles. The magma was thin, and it doubtless spread with considerable rapidity. Wherever the flow was impeded, broad lake-like expansions of the stream were formed.

This occurred at numerous points along the river, just above the narrow portions of the canyon. The surfaces of the ponded tracts are smooth, and the interrupted drainage leads to the development of meadows. The best example of this sort in the Shasta region is on Squaw Creek, four miles below Nabar. In some regions meadows developed in this way are of much importance. This is especially true in the Lassen Peak district, over 50 miles southeast of Mount Shasta, where a large part of the agricultural land was thus produced.

Although a comparatively late flow, the extrusion of the coulee which followed down the Sacramento occurred many centuries ago. This we are able to roughly estimate from the fact that the river has not only removed nearly all of the lava from the canyon, but has cut the canyon more than a hundred feet deeper into the solid rocks than it was at the time the lava followed its course. At many points along the river, between Upper Soda Springs and the tunnel four miles below the Sacramento River bridge, there are terraces of lava clinging to the sides of the canyon. These terraces are remnants of a once continuous coulee that reached to a point 50 miles from its source.

None of the Shasta coulees already mentioned have been glaciated. The surfaces of the flows retain their pristine roughness, and it is evident that they have been extruded since the glacial period.

The postglacial coulees form only a thin local veneer on the mountain slopes. Most of the erupted lava is older, and shows traces of glacial action. The great coulee which courses down the southeastern slope of the mountain, and ends in a prominent cliff between Mud and Squaw creeks, is well glaciated. Its surface at many points is either rounded and striated, or covered by glacial moraines. Mount Shasta was nearly as large during the glacial period as it is now. Since that episode it has gained but little more by addition of new lava flows than it has lost by degradation.

Near the summit, on the southwestern slope of the mountain, is a coulee of exceptional character. It is composed chiefly of lapilli, and forms the so-called red-and-black rock with which the climber on the usual trail up Mount Shasta becomes familiar at an elevation of from 13,000 to 14,000 feet. The material is wholly fragmental, and is the result of the last eruption from the summit of Shasta. The cinder-covered slope of this coulee, over

which the trail approaches the summit, has the appearance of a recent eruption, and it is possible that the last real volcanic activity about Mount Shasta occurred at this point.

A variety of surface features of the lava flows are illustrated by these coulees. The rough, angular blocks of Lava Park, the steam-torn, hackly surface of the trail flow, the cinder-covered slope of the flow near the summit of the mountain above McCloud Glacier, and the bubbly and ropy surface of the Elk Flat coulee, are good examples of the various types of lava surface. At the last-named locality the surface is in places covered with low domes, as if there were great bubbles beneath. This feature is better illustrated by one of the older lavas near Ash Creek, at an elevation of between 6,000 and 8,000 feet, where they have various forms rising sometimes to a height of 12 feet, with a diameter of 14 feet, and usually with well-marked radial jointing. The protuberance from the upper surface of the lava flow sometimes rises so high that it bends over, as if about to fall from its own weight.

On the southwestern slope of Mud Creek Canyon, below the Upper Falls, is a prominent glaciated cliff 75 feet in height. It is beautifully banded with gray and red. The bands vary from a small fraction of an inch to a foot in thickness, and are doubtless primary, originating at the time the lava was erupted.

Cones.—The pressure of the magma within the principal vent burst open the side of the mountain. Generally the molten material flowed out in a gentle stream, but occasionally it rose fountain-like, and resulted in the formation of a lava cone. On the northeastern slope of the mountain, near the lower edge of the snow, is a hill composed wholly of lava. Its form, as seen in the distant view, suggests that it is a lava cone directly over the vent from which the lava issued.

On the southern slope, as shown on the map (p. 246), ranging from 8,000 feet down to nearly 4,000 feet, is a series of five cones arranged in a curved line gently convex to the westward. All these hills are lava cones except the one at an elevation of 6,800 feet. Bear Butte is a fine example of a lava cone, and its form leads us to expect to find a crater in its summit. This expectation, however, is not well founded. The most conspicuous elevation of this kind about Mount Shasta is Cone Mountain, near the railroad at the western base. It rises over 2,000 feet above the surrounding country, and its slopes are inclined at an angle of

about 35 degrees. Cone Mountain was named by Professor Whitney in 1865 on account of its form. Although its steep slopes are formed chiefly of angular fragments, they are not cinders, lapilli, bombs, or blocks, such as result from explosive eruption. The solid lava since its extrusion, or perhaps in part at that time, was broken to pieces. There is no trace of a crater in its summit, nor of ejected fragmental material on its flanks, to indicate that the formation of the cone was to any degree due to explosive action. At the time of its extrusion the lava must have been very viscous to build up such a sharp cone. Had it been as liquid as that of Elk Flat, it would have spread out so as to form a plain, instead of a prominent mountain several thousand feet in height.

Of the cinder cones there are about half a dozen on the slopes of Mount Shasta; but they are, as a rule, less conspicuous than the lava cones. Their location may be seen on the map in cases where they are sufficiently elevated to be marked by one or more contours. On the western slope of Lava Park is a cinder cone over 200 feet high, with a well-preserved crater in its summit. Black Butte, northeast of Mount Shasta, has a double crater, with a very low rim of cinders. Those ejected from the crater are dark, and consist of the same sort of lava as that of which the most of Black Butte is composed. It is especially interesting to find scattered over the rim, and within this crater, fragments of pumice like that ejected by the last eruption from the summit of Mount Shasta. It indicates clearly that Shasta has been in eruption since the twin crater of Black Butte was formed.

Black Butte can scarcely be considered a part of Mount Shasta, although its lavas, as well as those of Ash Creek Butte, have contributed to the upbuilding of the mountain's base. Ash Creek Butte is a cone containing both lavas and cinders; and, judging from the amount of erosion it has suffered, it is of greater age than the other cones about Mount Shasta.

One of the most interesting cinder cones on the slopes of Mount Shasta is between the two branches of Panther Creek, at an elevation of 6,800 feet. It is a low, rounded dome, composed of red lapilli, and is sometimes called Red Hill. The summit has a regular convex curve, without the slightest suggestion of a crater to mark the hole from which the material was blown out. Lava has escaped from its base on both sides, and two short coulees course down the adjacent ravines.

The origin of such dome-shaped, craterless cinder cones is a matter of doubt; but a suggestion that they are due to glacial action on an ordinary cinder cone is found in the fact that this hill, instead of being exactly conical, is elliptical, with its longest axis parallel to the slope of the mountain. This view is strengthened by observations on a similar cone on the slope of Mount Shasta, about a mile northwest from the road at the summit in the pass between Mount Shasta and Black Butte. The unsymmetrical elliptical hill at this place is about 100 feet high, with one slope of 40 degrees and the other only 20 degrees. The top is irregular, dome-shaped, without a trace of a depression or crater to mark the point of ejection. On the summit are a number of large bowlders of lava, differing from that of which the hill is composed. They must have been carried there, and the most probable agent of transportation is glacial ice. The effect of glacial erosion on a cinder cone over which it passes, if not too long continued, so as to remove the cone entirely, would be to obliterate the crater, and make a more or less elliptical hill, with its longest axis parallel to glacial motion. The two elliptical cinder cones referred to are preglacial; while the others, having well-preserved craters, are postglacial.

Southwest of Wagon Camp is the cinder cone from whose base escaped the great coulee that extends down the Sacramento Canyon for 50 miles. It is nearly 600 feet high, with well-defined crater, surrounded by a rim of cinders. This is one of the most accessible cinder cones on the mountain.

Although the great body of Mount Shasta is made up of coulees of lava, it still contains a large proportion of fragmental material, and must be considered a mixed cone. On the north side of the canyon of Mud Creek, at an elevation of from 8,000 to 9,000 feet, and also below the timber line in both walls of the canyon, there are fine exposures of fragmental material ejected from the principal crater. With the exception of the cinder coulee already noted, this is the most important exposure of fragmental material ejected from the main vent.

Mount Shasta is a double cone. The two are so closely joined as to make but one cone below an altitude of 10,000 feet. Above this level the two cones may be distinguished. They mark the principal vents from which burst forth the coulees to build up the great mass of the mountain. All the other cones on the slopes of the principal one, whether composed of lava or

cinders, are subordinate, and make the position of subsidiary vents. Besides the two principal vents, there are traces of more than a score of subsidiary ones which contributed to the upbuilding of the mass. Many others may be found covered up in the growth of the mountain by the coulees coming down from the principal vents.

VARIETIES OF LAVA.—Rocks resulting from the solidification of molten material brought from the earth's interior by volcanic action are volcanic rocks. There are many varieties of volcanic rocks, arising from differences in structure and composition. Only three need be mentioned here. They are *rhyolite*, *andesite*, and *basalt*, and their distinction is based largely on chemical and mineralogic composition. Rhyolites contain in general somewhere between 66 and 80 per cent of silica; andesites, between 55 and 66 per cent; and basalts, between 45 and 55 per cent. Silica in a pure state is illustrated by the mineral quartz. It is a substance which is fused with great difficulty; and we may at once infer that rhyolites, being more siliceous than andesites and basalts, are less fusible. On this account rhyolites at the time of their eruption are generally much more viscous and stiff than basalts. The magmas of many basalts when erupted are almost as liquid as water. They spread far and wide in thin sheets, with even, level surface, like the water of a lake. The degree of liquidity of a magma at the time of its eruption determines the shape of the physiographic feature to which it gives rise.

The lavas of Mount Shasta are andesites and basalts. Although intermingled on the same slope, they are of more or less distinct eruption, and associated in certain cases with special topographical features. The most ancient variety of lava about Mount Shasta is one containing prominent crystals of black hornblende. The general color of the rock is light gray, and, on account of the conspicuous crystals of hornblende it contains, it is called hornblende andesite. It is exemplified in Cone Mountain. At the time of its eruption the magma was evidently quite viscous, so as to maintain steep slopes. On exposure to the weather it sometimes becomes reddish. It forms a large tract of the western slope of Shastina, and is exposed also near the foot of McCloud Glacier and other localities on the eastern and northern slopes.

The most abundant lava of Mount Shasta is hypersthene andesite,—a lava containing little or no hornblende, but much

hypersthene. It ranges in color from light and dark gray, often reddish, to black. This entire range of color may be seen on ascending the trail up the southwestern slope of the mountain. The trail is on hypersthene andesite all the way. In the later stages of growth, hypersthene andesite has contributed much more than hornblende andesite to the upbuilding of the mountain.

The third variety, basalt, is found only on the lower slopes of the mountain, forming nearly all of the cinder cones and the plains. In the cinder cones the lapilli of basalt are often deeply colored, red, yellow, or black. On the plains the basalt is generally gray, but sometimes verges upon black. It was usually more liquid at the time of its eruption than either of the andesites, and spread out, forming comparatively smooth surfaces, as at Elk Flat and the northern foot of Mount Shasta, west of Sheep Rock. If all the lavas that now appear on Mount Shasta had been as liquid as that of Elk Flat, the form of Mount Shasta would have been very different from that which it now has. Of this we can get a clearer idea by comparing Mount Shasta with Mauna Loa. Mauna Loa is 14,000 feet in height. Its lavas have such a high degree of liquidity, and retain their mobility so long after eruption, that the base of the mountain spread by them has a diameter of about 70 miles and an average slope of 5 degrees. The base of Mount Shasta is less than 20 miles in diameter, and its average slope nearly 15 degrees. Eighteen hundred feet below the summit of Mauna Loa its diameter equals that of the base of Mount Shasta, while the diameter of the latter in a corresponding position is less than 2 miles. The unlike form of the two mountains is attributable chiefly to a difference in the degree of liquidity of the lavas of which they were constructed.

Lava Caves.—In the gentle lava slopes about two miles southwest of Sheep Rock is Plutos Cave. It is shaped like a railroad tunnel. The bottom is generally flat, and covered by débris fallen from the sides and roof. In places the cave is nearly filled with such material. The walls have a shelly structure, and generally form a beautiful arch across the cave. An opening to the surface, affording an entrance to the subterranean passage, resulted from the falling-in of the roof. The cave, where best developed, is from 60 to 80 feet in height, and from 20 to 70 feet in width. It has been followed for nearly a mile without finding its termination, and it may be considerably longer. The crust or roof of the tunnel ranges from 10 to 75

feet in thickness, and the lava of which it is composed is full of cavities formed by the expanding steam in the lava at the time of its eruption. Many of these cavities are elongated parallel to the tunnel; that is, in the direction of the flow of the lava.

The sides and roof of the tunnel have caved in, so that the original lining of the cave has generally disappeared; but remnants here and there show that its surface was spongy, or marked by narrow, puckering folds. It is evident that the cave resulted from the escape of the molten interior of a coulee. The crust formed; but, before the whole mass was solid, the liquid escaped farther down the slope, and flowed out, leaving a cavity within the coulee's crust. The tunnel is lined here and there by blisters and froth-like exudations of lava from the sides; but no distinct stalactites and stalagmites of lava, such as Professor Dana reported from the lava tunnels on the slopes of Mauna Loa, were seen in Plutos Cave.

The surface of the country about Plutos Cave is flat, but rough, with irregular domes and blisters of lava. Judging from the hollow sound one hears in walking or riding over many portions of the lava about the base of Mount Shasta, it is probable that there are numerous caves in that region. Such caverns are known to exist not only at the northwestern base, but also at the southeastern, in the neighborhood of Elk Flat. This feature of vulcanism is especially well displayed in the so-called lava beds 50 miles northeast of Mount Shasta, where the Indians under Captain Jack so long successfully defied our troops. Many of the tunnels have caved in, leaving the country traversed by deep, rocky canals, such as to render it almost impassable at right angles to the flows. During the winter, snow drifts into the canals, and forms sufficient accumulation of ice in some cases to last all summer, furnishing a scanty supply of water in a region where it is otherwise scarce.

Meteorological Conditions.—In strong contrast with the circumstances attending the upbuilding of Mount Shasta when it was an active volcano, belching forth streams of fiery lava, are its arctic conditions of to-day, with its summit wrapped in eternal snow. It has long been the field whereon was fought the battle between the elements within the earth and those above it. In the early days the forces beneath were victorious, and built up the mountain in the face of wind and weather; but gradually the volcanic energy reached its climax, declined, and passed away.

The loss of heat was succeeded by icy cold, which opened the way to more vigorous, unrepelled attack of those destructive agencies that are now reversing the process, and slowly but surely wearing the mountain away, and reducing it toward a general level.

On the slopes of Mount Shasta, between its base and its summit, there is a wide range in meteorological conditions, determined by differences of altitude, thus dividing the mountain into climatic zones. On the middle slope is the great forest belt; above it, encircling the top, is the cold, moist zone; and at the very lowest points of the base of the mountain, in Shasta Valley and Elk Flat, there is a warmer, dry zone.

The lower, middle, and upper zones differ widely not only in temperature, precipitation, and vegetation, but also in their slopes and consequent gradational features.

Lower Zone.—The influence of temperature on precipitation, and the limits which it throws about arboreal vegetation, are here most forcibly illustrated. This zone is not continuous about the mountain. It is fully developed only at the northwestern and southeastern bases of the mountain in Shasta Valley and Elk Flat. In Shasta Valley, at an elevation of about 3,000 feet above the sea, where the average temperature is high as compared with that upon the mountain itself, the precipitation is always in the form of rain, but not sufficient in quantity, especially on account of its unequal distribution throughout the year, to support more than a scanty growth of stunted trees. In the autumn, storm clouds gather about the summit, and showers become frequent, spreading over the land in copious rains. Before the spring, eight ninths of all the annual rain has fallen, and the country is brilliant with living green. As summer advances, the refreshing showers disappear, and the cloudless sky affords no protection from the burning sun; the bright green fades away, and the earth gradually assumes that uninviting, seared aspect which pervades all nature in the season of drought.

Middle Zone.—On the middle slopes of the mountain, by the cooling influence of altitude, the rainfall is gradually increased, and the vegetation is luxuriant. From the limits of this zone, arboreal vegetation gradually diminishes in stature and number toward the upper and lower zones. The trees are almost wholly coniferous. Among nearly a score of species the sugar pine is monarch, frequently attaining a diameter of 12 feet and a height of over 200 feet. Farther up the mountain these gradually give

way to firs, whose tall, graceful forms are in perfect keeping with the majestic mountain behind them. Their black-and-yellow spotted trunks and branches, draped here and there in long pendent moss, present a weird, almost dismal aspect, making a fit promenade for the mythical deities supposed by the aborigines to inhabit the mountain. To assume that in the timber belt the slopes of the mountains are everywhere covered with majestic trees would certainly be wide of the truth, for within the forests are large treeless tracts sometimes hundreds of acres in extent. From a distance these green, velvety acres appear to be very inviting pastures, and present the most desirable path of ascent. A closer examination, however, discovers to the observer, that, instead of grass, these green fields are clothed in such a dense shrubbery of manzanita, *Ceanothus*, and other bushy plants, as to be almost impassable. One attempt to cross a patch of chaparral, or "devil's acre," as it is sometimes appropriately called in Western vernacular, will convince the traveler that his best path lies in the forest.

Upper Zone.—The timber gradually diminishes in stature as it ascends the mountain from an altitude of 7,000 feet to the region where the precipitation is generally, if not always, in a solid form,—snow in winter, and sleet in summer. On the southwestern slope the forests cease abruptly at an elevation of about 8,000 feet, but upon the opposite slope they diminish gradually to the region covered by glaciers. The tree which climbs highest is *Pinus albicaulis.* Its stem becomes shorter and the top flattens as one ascends. At an elevation of about 9,000 feet the branches are spread on the ground, so that not infrequently the pedestrian finds his best path over the tree tops. Beyond these, on the snowless slopes, are found only scattered blades of grass, and the welcome little *Hulsea*, the edelweiss of our Alpine regions, with its bright flowers to alleviate the arctic desolation of the place. The red and yellow lichens cling to the rocks, and the tiny *Protococcus* flourishes in the snow; so that one is occasionally surprised, on looking back, to see his "bloody" footprints.

In the Alps, between the zone of forests and the snow, are often found extensive pastures, where the herds which furnish milk for the celebrated Swiss cheese graze during the milder seasons of the year. In northern California similar pastures do not occur about the snow-capped summits, probably on account of the unequal distribution of the annual rainfall.

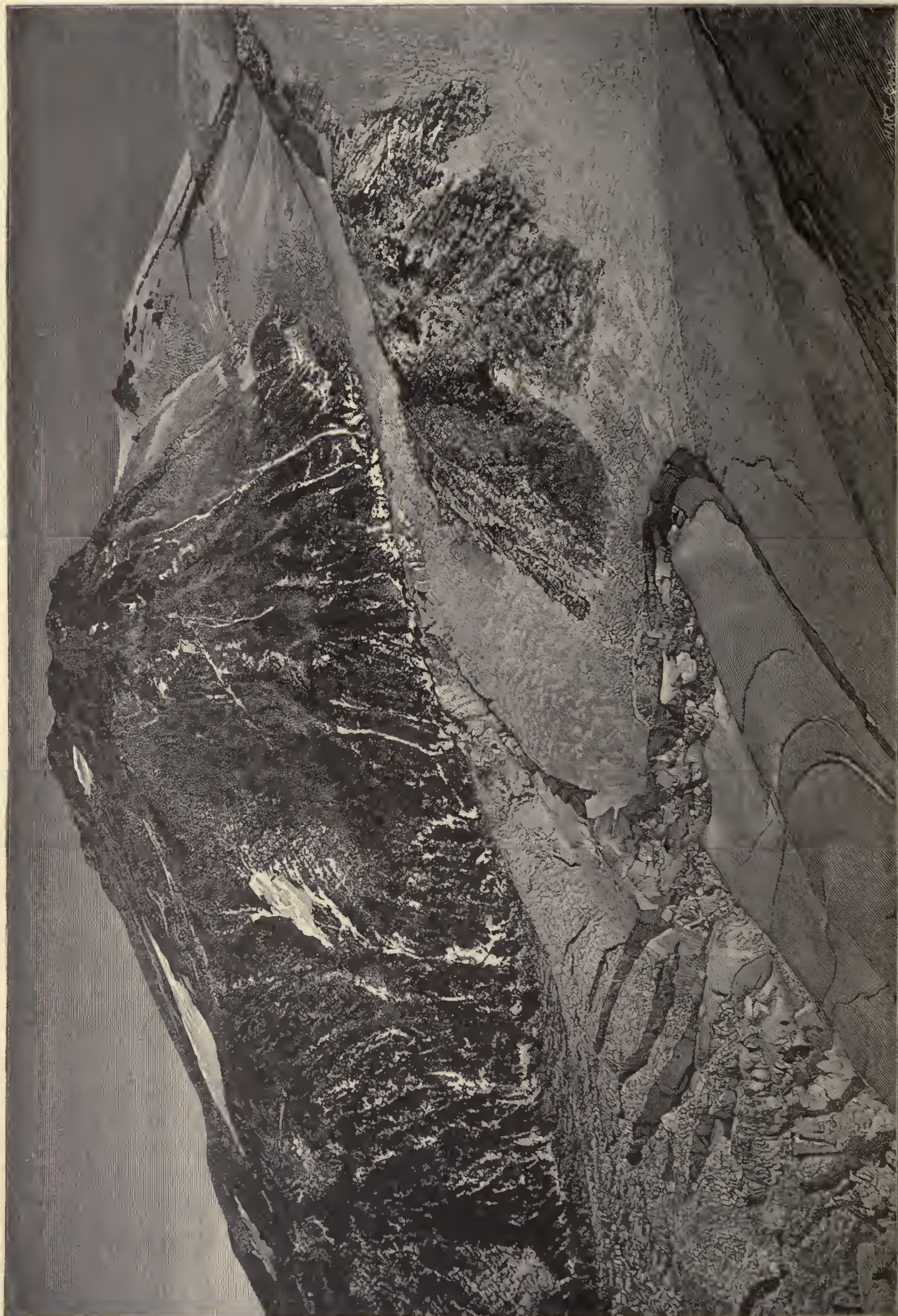

Fig. 6.—Head of Whitney Glacier, Mount Shasta, California.

Glaciers.—Great interest attaches to the glaciers of the upper portion of Mount Shasta. There are five in number, and all are found side by side, forming an almost continuous covering for that portion of the mountain at an altitude of about 10,000 feet. On the northwestern slope of the mountain is Whitney Glacier, with its prominent terminal moraine; to the eastward is Bulam Glacier, with a large pile of débris at its lower end; next comes the broad Hotlum Glacier, and then the Wintun. McCloud Glacier, which is the smallest of the group, lies on the southeastern side of the mountain.

Whitney Glacier.—Whitney Glacier is more like those of the Alps than any other one of the group. Its snow field lies on the northwestern slope of the mountain, from whence the icy mass, with well-defined limits, moves down a shallow depression between Shasta and Shastina. Its width varies from 1,000 to 2,000 feet, with a length of about $2\frac{1}{5}$ miles, reaching from the summit of the mountain down to an altitude of 9,500 feet above the sea. It is but little more than a decade since the first glaciers were discovered within the United States; and the largest of them, about the culminating point of the Cascade Range, would perhaps appear Lilliputian beside the great glacier of the Bernese Oberland; and yet they are as truly glaciers. In the upper portion of its course, passing over prominent irregularities in its bed, the Whitney Glacier becomes deeply fractured, producing the extremely jagged surface corresponding to ice falls of the Alpine glaciers. Lower down the crevasses develop, as shown in Fig. 6; and these, with the great fissure which separates the glacier from the steep slopes of Shastina, attest the motion of the icy mass. They frequently open and become yawning chasms, reaching 100 feet into the clear green ice beneath. Near its middle, on the eastern margin, Whitney Glacier receives contributions of sand, gravel, and bowlders from the vertical cliffs around which it turns to move in a more northerly direction. In this way a prominent lateral moraine is developed. From the very steep slopes of Shastina, on the western side, the glacier receives additions in the form of avalanches. Here the snow clings to the rocky bed until the strain resulting from its accumulation is great enough to break it from its moorings, and it rushes down upon the glacier below. The most striking feature of Whitney Glacier, and that which is of the greatest interest from a geologic point of view, is the débris (moraine) it brings

contrasted with the other glaciers of Mount Shasta. There is no well-marked terminal moraine, although there are accumulations of débris on the northern side near the end. The detritus is apparently swept out of the canyon by Ash Creek as fast as it is brought there by the glacier, and thus the accumulation of a terminal moraine is prevented.

McCloud Glacier.—On the southeastern slope of Mount Shasta, at the head of a large canyon, is the McCloud Glacier. It adjoins the Wintun, and is the smallest glacier of the group. Notwithstanding its diminutive size, its crevasses and the muddy stream it initiates indicate clearly that the ice mass continues to move. The amount of morainal material upon its borders is small, and yet, of all the glaciers about Mount Shasta, it is the only one which has left a prominent record of important changes. The country adjacent to the southwestern side of Mud Creek Canyon has been distinctly glaciated, so as to leave no doubt that McCloud Glacier was once very much larger than it is at the present time. The rocks over which it moved were deeply striated, and so abraded as to produce the smooth, rounded surface so common in glaciated regions. At the time of its greatest extension the glacier was over 5 miles in length, and occupied an area of at least 7 square miles, being twenty times its present size. Its limit is outlined at several places by prominent terminal moraines, which mark stages in the recession of the glacier. The thickness of the glacier, where greatest, was probably not more than 200 feet; for several hills within the glaciated area were not covered, and the striated surfaces and moraines do not extend up their slopes more than 200 feet. The thickness of the glacier is completely in harmony with the limited extent of its erosion. Although the rocks are distinctly planed off, so that the low knobs and edges have regularly curved outlines, it is evident that a great thickness has not been removed by the ice, and that the period of ice erosion has been comparatively brief. During the lapse of time, however, there have been climatic oscillations, embracing epochs of glacial advance and recession.

With the exception of McCloud Glacier, there are no records upon the slopes of Shasta that any of the existing glaciers were ever very much larger than at present.

At the southwestern foot of the mountain, near the railroad, there is a large area covered by glacial moraine in the form of rounded and irregular hills, inclosing many small basins, above

which they rise rarely as much as 30 feet. This moraine is composed of the older lavas of that portion of Mount Shasta, and demonstrates that during the glacial period the southwestern slope of the mountain had an ice stream 10 miles in length. The glaciers on the other portions of the mountain must then have been much larger than now, and it is probable that their records have to a large extent been buried beneath later eruptions.

SPRINGS.—Made up, as it is, of imbricated coulees and fragmental material, all of which is more or less porous and full of fissures, Mount Shasta absorbs the principal portion of the precipitation on its slopes. The rainfall on Mount Shasta is large. The amount of water that reaches McCloud, Sacramento, and Shasta rivers by surface drainage is very small. By far the greater portion of the drainage of Mount Shasta is subterranean. This is shown by the large springs about its base.

The Big Spring, above Sissons, is a fine example, giving rise to a good-sized stream, that by some has been considered the head of the Sacramento. Moss Brae Falls are produced by springs issuing from between the coulees of Mount Shasta on the side of the canyon of the Sacramento, and cascading over the grassy slope to the river below.

The greatest springs are those in McCloud Canyon, where the river cuts the southern edge of the lavas from Shasta on the border of Elk Flat. Large volumes of water issue from the river bank, and the size of the stream is doubled by their addition.

Squaw Creek originates in springs. The flow is copious, regular, and clear as crystal. It is a beautiful, transparent, limpid stream, strongly contrasted with its muddy neighbor coming down from McCloud Glacier.

The greatest springs are low down the mountain slope, although there are many smaller ones above.

On the summit of the mountain there is a small group of openings from which hot sulphurous gases are continuously escaping. The place is sometimes referred to as the Hot Spring, but, as gases only escape, it is more properly called a *solfatara*. The earth about the holes is warm, but, as the vapors are noxious, the place cannot be used as a source of heat for the camper who may wish to remain on the cold summit over night. Down the northern slope, between Whitney and Bulam glaciers, several hundred feet below the summit, is another solfatara. These are the last palpable vestiges of heat upon the mountain.

Streams.—A glance at the map (p. 246) reveals a marked irregularity in the distribution of streams on the slopes of Mount Shasta. They are nearly all on the eastern half of the mountain, and associated directly with the glaciers. The reason for this distribution is found in the prevailing southwesterly winds of the region. These are so strong and enduring that the branches of the exposed trees high up on the slopes are blown around to the northeastern side. It is only where winds continue to blow steadily for a long time in one direction that such effects can be produced. The winter storms which furnish the Shasta snow are driven by such winds, and the snow finds a resting place only on the lee side of the mountain, and there the glaciers are formed.

Though all the streams depend for their water supply upon the snow of the summit, some get it indirectly through springs, while others flow directly from the glaciers. Squaw Creek has its source in springs, while Mud Creek originates in McCloud Glacier. Each stream is a good example of its kind. They are close together, and yet strongly contrasted in appearance. Squaw Creek is a beautiful, clear, refreshing stream, with inviting banks; while Mud Creek, as its name implies, is full of sediment, and its banks are lined with gravel, sand, and mud. The source of the detritus is the glacier, which, as it gradually moves down the mountain slope, armed with many rock fragments, files off the surface, and produces the mud, sand, and gravel for the stream to carry away. Glacier streams vary greatly in volume, not only with the season, but also with the time of day. During the winter there is little melting of snow and ice, and the streams have little water; but during the heated summer the supply is copious and floods prevail. For the same reason, also, the stream varies between day and night. Thus the returning sun awakens the sleepy stream, and sends the thrill of life into the mountain's circulation.

Most of the glacier streams sink on reaching the lower slope of the mountain. As the water supply declines, the point at which the stream disappears in its bed retreats farther up the slope, to return again with the diurnal pulsation of another sun. In the long streams there may be several pulsations at the same time. The hours of advance and retreat of the stream are determined chiefly by the grade, and by distance from the glacier.

Falls.—It is readily understood that the abrupt termination of the coulees below leads to the development of falls in the

streams which find their way down the mountain slope. All the streams of considerable size have such falls, and in the same stream several may occur. Mud Creek has three,—one within the forest belt, another near the timber line, and a third more than a mile farther up the stream. Ash Creek Fall, near the timber line, has a height of nearly 400 feet, and the stream plunges into a deep canyon. It is one of the most impressive falls of the mountain. Bulam Creek and Whitney Creek have similar falls of great height; but the streams are small, and on this account they are less impressive than those of Ash Creek.

Degradational Features.—We have considered those features which originate in the upbuilding of the mountain, the meteorological circumstances to which it gave birth, the forests, glaciers, streams, and falls that followed. Let us now turn our attention to the degradational features developed by these conditions. The three zones into which the mountain slope is divided by its meteorological conditions are well marked by the consequent degradational features. Instead, however, of designating these zones according to elevation, they may in this case be named, from the characterizing feature, the "Plain Zone," the "Canyon Zone," and the "Cirque Zone" respectively.

Plain Zone.—In this zone fully developed plains predominate, and there is but little erosion. Most of the streams coming down from above the timber line sink when they reach the plain about the base of the mountain, and the drainage becomes subterranean. Dotted stream lines on the map indicate that the stream beds are usually dry. Whitney Creek, Inconstance Creek, Brewer Creek, Ash Creek, and many smaller streams disappear from the surface during a large part of the year. All streams are enfeebled by subterranean leakage by the time they reach the Plain Zone, and the gentle slopes leave them little power of corrasion.

The banks of the glacier streams are lined with gravel, sand, and mud brought down from above. During the hot season, when the floods come from the melting snows of the upper zone, the streams swell far beyond their winter limits, and carry away the accumulated débris. The low grade permits the streams to do but little more than this. The degradation of the mountain's base is very slow. The streams flow in beds near the general level, and degradational features are not conspicuous.

Canyon Zone.—The Plain Zone passes rather abruptly upward into the Canyon Zone, with which it is in marked contrast.

The Canyon Zone is in the forest belt. The protective covering of living and fallen leaves breaks the dash of the rain. The roots bind the soil together, and the shade regulates the sudden changes and wide range of temperature. Thus the forest protects the slope on which it grows, and tends to prevent rapid degradation. This difference, however, does not modify to any considerable extent the corrasion of the tumultuous streams from the glaciers. Heavily armed with gravel and sand, they act upon their narrow beds somewhat as a file, continually moving down the slope, and cut deep canyons across the forest belt.

The canyon of Mud Creek is the largest. It has a length of about 5 miles, and a depth where best developed of about 1,000 feet. At the timber line it is not so deep, its slopes are less precipitous, and the canyon is crossed by a rude trail. Elsewhere it is almost impassable for horses. The middle falls of Mud Creek are near the timber line. Above this point the southwest wall of the canyon is made up largely of solid coulees, while the opposite side is composed chiefly of fragmental material, on whose slopes is developed the pinnacled topography to which such formations frequently give rise. The canyon is deepest a mile below the timber line. Its sides have a slope of about 37 degrees, with occasional columnar cliffs of tufa, reaching in some cases a height of 50 feet. The rocks in which this portion of the canyon is carved are almost wholly fragmental. It is treacherous climbing ground, for the rocks are fragile, and afford unreliable support. They are more or less distinctly but imperfectly stratified, and dip away from the mountain at an angle of from 8 to 12 degrees. The slope of the mountain is approximately parallel to that of the layers of fragmental material, and suggests that the inclination of the layers was determined by that of the slope on which they were deposited. Coulees of lava, where observed, are parallel to the same slope, and it is apparent that some of the flows followed earlier canyons down the mountain slope. The three falls in this canyon are all over solid coulees.

The canyon of Ash Creek is neither so long nor so deep as that of Mud Creek, but is cut in harder rocks. It ends above at the falls, where the stream plunges over a mass of lava nearly 400 feet in thickness. The canyon walls are of the same material near the falls; but beyond, the coulees are less distinct, and fragmental material increases. Two miles below the falls a

stratum of pumice 20 feet thick may be seen lying between somewhat thicker beds of sand and bowlders. The slopes, although steep, are generally wooded, and landslides are less frequent than in Mud Creek Canyon. Striated rocks *in situ* occur near the bottom of the canyon, over two miles below the present terminus of Wintun Glacier.

Brewer and Inconstance creeks are small, and their canyons are of corresponding size. On the other hand, Bulam and Whitney creeks are larger, and have carved canyons, in some places 600 feet deep, down the northern slope of the mountain.

Cirque Zone.—The Canyon Zone extends up the slope of Mount Shasta to an elevation of nearly 10,000 feet. At the upper ends of the canyons their walls retreat, and the valleys become shallower, and spread out in fan shape, forming cirques against the mountain summit. The glaciers occupy cirques. Those of McCloud, Wintun, and Bulam glaciers are the best developed. The snow slides in from the sides and head of the cirque, and the corrasion is glacial. At lower levels the snow and ice melt, forming streams of water armed with glacial gravel and sand, with which to scour their beds and cut the canyons of the forest belt. The cirques are wholly above the timber line, and are of glacial origin. The divides between them are usually sharp, jagged ridges, while in the Canyon Zone they are broad and even. In this last feature (the broad and even divides) is found evidence of the comparative youth of Mount Shasta. Its slopes are smooth; they have suffered but little from general degradation since the volcanic forces completed its construction. In this respect it is strongly contrasted with Mount Rainier, which has been deeply sculptured by ice and water; and yet Mount Rainier is less than halfway in the course of erosion toward exposing its volcanic neck, which occupies the vent through which the lava came up to the surface. While the early stage in the degradation of volcanoes does not differ materially from that of other conical mountains, the late stage in which the volcanic neck appears is peculiar and especially characteristic. That Mount Shasta has a great core of solid lava in its center, from which, when the coulees have been washed away, a conspicuous volcanic neck may be developed, there can be no doubt; but, if the process of degradation proceeds as now, without acceleration, it will be many centuries, even geologically considered, before the neck is fully brought to view.

Age.—The upbuilding of Mount Shasta is but a matter of yesterday compared with the lapse of ages since the birth of some of its neighbors. The complex group of mountains on the west, embracing Scott, Trinity, Salmon, and Siskiyou, all of which belong to the Klamath Mountains, are composed in large part of ancient crystalline rocks of both aqueous and igneous origin. Through these the Klamath and the Sacramento rivers have cut deep canyons. The canyon of the Sacramento was cut down to nearly its present level, and the mountains sculptured into existing forms, long before the eruption of Mount Shasta had ceased; and a fiery flood of lava, escaping from the southern slope of Mount Shasta, entered the Sacramento Canyon, and followed it for 50 miles.

Towering more than a mile above its neighbors, perhaps the youngest of the group, Mount Shasta is the last of a long series of volcanoes in the Cascade Range, stretching northward to Mount Rainier in Washington. This range, composed chiefly of volcanic material, is cut across by the canyons of Columbia and Klamath rivers. In the former, beneath a thickness of 3,500 feet of lava, are found strata containing Tertiary fossils. At the southern base of Mount Shasta, in the canyon of McCloud River, similar beds of volcanic débris are found, but without fossils. It is evident that the main mass of the Cascade Range and its volcanoes originated in recent geologic times; and from the fact that solfataras, fumaroles, and hot springs are common on their slopes, they cannot be counted among wholly extinct volcanoes.

Active volcanoes occur in Alaska, but there is some doubt as to when and where the last volcanic eruption in the United States south of Alaska may have occurred. The evidence seems conclusive that an eruption took place as late as 1843 from Mount Baker, and also from Mount St. Helens in Washington.

Mount Shasta is a typical example of a large volcano. Its upbuilding resulted from long-continued series of intermittent eruptions. The attack of the weather increased with the height of the mountain, and reached its climax with the decadence of volcanic energy. During the brief period in which the weather has exercised supreme control, the slopes of Mount Shasta have been deeply cut with canyons, and cirques have been outlined about its lofty summit. In the course of geologic time it will be swept away, but for ages yet to come it will remain one of the grandest mountains on the face of the earth.

THE PHYSICAL GEOGRAPHY OF SOUTHERN NEW ENGLAND.

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Southern New England is for the most part a slanting upland, reaching elevations of from fifteen hundred to two thousand feet in Vermont and western New Hampshire near the Massachusetts line, and descending gradually to the coast on the east and south. The upland is overlooked by occasional mountains of moderate height, such as Monadnock: it is intersected by numerous valleys, deep and narrow like that of the Deerfield, or broad and open like that of the middle Connecticut. Its shore line is ragged, with reëntrant bays between projecting headlands, and sounds behind outlying islands.

The heads of the larger bays were early chosen as places of settlement, and there a number of thriving commercial cities have now grown. The low coastal border of the upland near the cities is occupied by a comparatively dense suburban and rural population. The inner valleys serve as the paths of railroads leading to numerous manufacturing villages and cities. The higher parts of the upland are sparsely settled by a decreasing agricultural population, and the mountains above the upland are practically uninhabited.

THE UPLAND OF SOUTHERN NEW ENGLAND.

General Features.—The gently slanting upland is the most important geographical feature of this region. Omitting from consideration for the present the mountains that here and there overlook it, and the numerous valleys that are worn beneath it, let us consider the form and origin of the upland itself. Ascend

FIG. 1.—Upland of Western Connecticut, near Bristol.
(Photographed by F. L. Olmsted, Jr.)

a hill that reaches the general upland level, and note how even the sky line is on all sides; how moderate the inequality of the surface would be if it were not for the few mountains that rise above it, and the many valleys that sink below it. Looking around the horizon, the slightly rolling high-level surface of one hill after another approaches the plane of the circular sky line. It requires but little imagination to recognize in the successive hilltops the dissected remnants of a once even and continuous surface, beneath which the valleys of to-day have been eroded. The former continuity of the now separated hilltops is so manifest, when it is once perceived, that it is well to describe the region as *an upland* or as *a dissected upland,* thus emphasizing the original continuity of the now dissected upland areas, and at the same time counteracting and correcting the belief, prevalent in the minds of those who dwell in our valleys, that southern New England is simply a region of disorderly hills.

Not less notable than the former continuity of the dissected upland is the want of sympathy between its surface and the structure of the rock masses of which the region is composed. The slopes and crests of the hills often expose their structural rock ribs in projecting ledges; the disordered attitude of the rocks is plainly exhibited in stream banks, quarries, and railroad cuts; but, however they stand, they are evenly cut off when they reach the upland surface, just as the fibers of a great tree are cut across at the even surface of its sawed stump. This is an important matter, for upon it chiefly turns the correct interpretation of the origin of the upland.

The upland is most easily recognized where it stands at a considerable elevation, for here we find the strongest contrast between hilltop and valley floor. The broad, high-level areas between the Deerfield and Westfield valleys, or the Westfield and Farmington valleys, in western Massachusetts, offer admirable illustrations of its character. The upland can thence be traced southward, past many deep, trench-like valleys, such as that of the Naugatuck above Waterbury, Conn. It gradually descends to the sea level at the shore of Long Island Sound. The view westward from the summit of the Hanging Hills, near Meriden, Conn., shows the upland beyond the Connecticut Valley lowland with a remarkably even sky line. It truly resembles a plateau thereabouts, and so it may be called. An excellent sight of the upland farther east may be obtained from Great Hill, a

FIG. 2.—View from Hanging Hills, across Connecticut Valley Lowland, to the Western Upland beyond.

(Photographed by F. L Olmsted, Jr.)

little north of Cobalt station, on the Air Line Railroad, a few miles east of Middletown, Conn. Here attention is first attracted by the beautiful valley of the Connecticut River, on its way to the Sound at Saybrook (of which, more below); but, on turning to examine the upland in which the valley is sunk, the even sky line is still perceived to be its most striking characteristic. Farther north, in Massachusetts again, the quiet hill town of Shutesbury, easily reached by stage or on foot from the Fitchburg Railroad, near by in the valley of Millers River, commands a wide prospect over the even upland, and down into the valley by which the upland is there so deeply dissected. Near Gardner, the Fitchburg line passes over the divide between the basins of Nashua and Millers rivers, and traverses the upland for a short distance. Broad views then open out on either side, presenting the upland country in a very different aspect from that in which travelers by rail ordinarily see it; for most of our railroads follow valley floors. North of Boston, the hills back of Waltham, Arlington Heights, and the Middlesex Fells as seen from the hills of Somerville,—or even from the State House dome,—exhibit a comparatively even sky line, gradually descending eastward toward Lynn. West of Narragansett Bay the upland has a well-defined, even-summit surface, gently descending southward, as in Connecticut; and so on, at many other places. There is hardly a village in southern New England—except on the sandy lowland of the southeast—from which a willing observer cannot see a part of the upland in an afternoon's walk.

Origin.—Still postponing the consideration of the surmounting mountains and the intrenched valleys, let us inquire into the origin of the once even surface of the upland. At the time before the valleys were worn in it, it was a broad, gently rolling plain of moderate relief, only here and there interrupted by the mountains that rose above it. It cannot have then been a young marine plain formed under the sea and revealed by uplift, like the coastal plain which now borders our southern Atlantic and Gulf States; or a young lacustrine plain, once the floor of a lake from which the water has been withdrawn, like the desert plains of Utah and Nevada: for plains of these classes consist of bedded and loose-textured sands and clays, whose nearly horizontal strata closely accord with their almost level surface. The New England upland consists of rock masses of many different kinds, whose texture is for the most part thoroughly indurated, and whose at-

titude is greatly and irregularly inclined. Manifestly the ancient upland cannot be classed with either marine or lacustrine plains.

There are slanting or nearly level plains in certain parts of the world which have been formed by the weathering and wasting-away of a mass of overlying rock layers, thus exposing a horizontal or slightly inclined resistant stratum of indurated rock, on which further progress of weathering is long delayed. Such, for example, is the upland plain in which the gorge of Niagara is cut; but in these stripped plains, or *structural plains*, as they may be called, there is necessarily a close sympathy between the shape of the surface and the attitude of the resistant stratum which determines it. Surely this is not the case in New England; for here, although the rocks are indurated, they stand in all attitudes with respect to the upland surface,—here inclined to the east, there to the west; here gently slanting, there steeply plunging or even vertical. The generally even surface of the upland shows practically no sympathy with this diversity of structure, but passes indifferently across all the inclined rock masses. The New England upland cannot, therefore, have been a structural plain.

There is a kind of plain that results from the destructive action of weather and water, by which any land area, whatever its original form, is worn down so smooth, and so close to sea level, that it cannot be worn any lower. Although thus easily and simply stated, the possibility of producing plains in this manner is one from which an unaccustomed mind instinctively shrinks on account of the enormous time that it must require. The small attention at present given to land sculpture in the study of geography is here to blame. Early grammar-school teaching should present the general idea of weathering of rocky hillsides and the transportation of the rock waste down the slopes to the sea, thus preparing the way for understanding the great results of these simple processes when long continued; yet nowadays even the teacher may hesitate to think that land erosion has anywhere in the world advanced so far as to consume high hills, and reduce them to lowland plains. This idea is not commonly familiar, and it is generally given a cool reception when first met. Many text-books now in use cite deep valleys as the best examples of long-continued erosion; but it is manifest that, where the valley sides have wasted away so as to consume the interstream hills, a greatly increased period of erosion must have elapsed. Worn-down countries or plains of denudation, and not

deep valleys, should therefore be introduced as examples of what erosion can do if time enough is allowed; and the earlier this important generalization becomes familiar to young scholars, the more frequently and easily can they apply it afterwards.

Now we must inquire whether the ancient upland of New England, before the valleys were cut in its then even surface, was a plain of denudation; and the methods of this or of any similar inquiry should be carefully and consciously perceived. We must, on the one hand, study the physical features of the region under consideration until they can be justly generalized; we must, on the other hand, reason out what would be the essential peculiarities of a plain of completed denudation, guiding ourselves in this inquiry by accepted geological principles. We must then compare the results of these two lines of work; and if the expectations of our reasoning match the generalized facts of observation, it may be as a rule fairly maintained that the reasoning has led to a correct explanation of the facts, or at least that the explanation may be adopted provisionally while it undergoes further scrutiny. This method has already guided us in inquiring whether the New England upland was originally a marine coastal plain, a lacustrine plain, or a stripped structural plain, the result being negative in each case.

The facts of form and structure of the New England upland have already been sufficiently stated in generalized form. They may be verified by hundreds of observers in all parts of Massachusetts (except, as already stated, in the sandy southeastern lowland), Rhode Island, and Connecticut, as well as in southern Vermont and New Hampshire. The theoretical expectations regarding a plain of denudation must now be reasoned out. Whatever the initial form and structure[1] of the region, it must be worn lower and lower as long as it stands still with respect to sea level, and suffers under the general attack of weather and water. The valleys are deepened first, until the slope of their rivers is reduced to a gentle grade. The hills are much more slowly worn down; but as long as they have a slope to the streams, and as long as the streams descend to the sea, the wasting of the hills continues. The most resistant rocks are the last

[1] It should be observed that the term *structure* is used throughout this monograph to refer to the internal arrangement of rock masses, and not to the succession of superficial features, as it is sometimes employed in geographical descriptions. The latter use is objectionable.

to be worn down, but all must go in time. When at last worn close to sea level, the surface must be practically indifferent to the attitude of the rock masses. There can be no essential sympathy between surface and structure, such as has been stated to characterize young, unworn marine or lacustrine plains, or stripped plains. The almost sea-level surface to which a region may ultimately be reduced must pass indifferently across the structure of its rock masses.

The Upland is an Old Peneplain.—This peculiar feature —indifference of even surface form to disorderly internal structure—now appears to be a common characteristic of the old upland of southern New England, and of a theoretical plain of denudation: hence the upland may be fairly enough provisionally regarded as an ancient plain of denudation. It should be noted, however, that, according to this explanation, it is not necessary to suppose that the upland of New England or of any other similar region was worn down absolutely and completely to sea level, or *baselevel*, as it is generally called. The process of denudation may be interrupted in a penultimate stage, when the region had been reduced to moderate relief, and before it had been worn down perfectly flat. It might then be called, not a plain, but a *peneplain*, of denudation.

The discordance of the upland surface and the rock structure is so marked a characteristic of New England, and is so fully and reasonably explained by the theory of the peneplain, that it would be fair to conclude at once that the formerly even upland really was a peneplain, worn down under the long attack of the weather, if it were not for a possibility that smooth plains of denudation may be produced by another process, namely, by the attack of the seashore waves. If a continental mass stand still for a long time with respect to sea level, while the sun continues to shine, the winds to blow, and the waves to roll, then the margin of the continent will suffer from the beating of the surf: the sea will encroach on the land, eating it away, and reducing it to a comparatively smooth submarine platform at a moderate depth beneath the water surface. May not the New England upland have been formed in this way, and afterwards raised from beneath the sea? The surface of the submarine platform would, like that of the subaërial peneplain, be indifferent to the rock structures across which the shore waves had cut their way: hence the chief test on which we relied for detection of the peneplain

does not serve to distinguish it from the platform. What we now need is some further test by means of which these two kinds of plains of denudation may be discriminated.

The needed test is found in the arrangement of the rivers; but, while the argument thus far pursued is essentially simple, its further extension is unfortunately complicated, and particularly so in its application to New England. It must suffice, therefore, to present it only in outline.

During the long-continued attack of the weather necessary for the production of a subaërial peneplain, the little streams gnaw at their head waters, and search out the weaker rock masses on which to extend their valleys. As these growing valleys increase in length, they thus become well adjusted to the structure of the region that they drain. Peneplains have, therefore, not only a surface form that is indifferent to internal structure: they have also a drainage system that is for the most part well adjusted to the weaker parts of the structure; and this adjustment is maintained or even further improved if a new uplift of the region afterwards allows deeper dissection.

During the long-continued attack of the shore waves necessary for the production of a broad submarine platform, the valleys are extinguished as the land is cut away. When the platform is afterwards raised above sea level, and streams gather on it again, they assume such courses as the slight inequalities of the uplifted platform shall determine, and hence have about as indefinite relation to structure as the surface has. Uplifted platforms have therefore, when they arise above the sea, and for some time thereafter, a drainage system that is essentially indifferent to the rock structure.

It would be easy to apply the test thus deduced if the geological structure of New England were as simple as that of middle Pennsylvania; but unfortunately such is not the case. The arrangement of the rock masses in the New England upland is excessively complicated; moreover, the glacial invasion (of which, more below) has been a disturbing agency by throwing many streams into new courses. It would be venturesome at present to make any general statement regarding the adjustment or indifference of our streams and structures, and the question would have to remain in doubt were it not for evidence that may be borrowed from New Jersey and Pennsylvania. The upland of New England is continuous with corresponding uplands in those

States,[1] where the river test has been successfully applied. The subaërial origin proved for the more southern peneplain may be fairly accepted for the more northern one as well.[2]

Reflections suggested by the Origin of the Upland.— When the belief clearly enters the mind that the upland of southern New England is really a peneplain of denudation, it arouses a number of interrogative reflections. In the first place, inquiry springs up as to the amount of material that has been worn away in the production of the peneplain. Look once more at the character of the upland rocks: they are crystalline schists and gneisses for the most part, whose minerals are never formed at the surface of the land or on the floor of the sea, but only deep within the crust of the earth under great pressure and at comparatively high temperatures. Besides these rocks, there are many intrusive granites, felsites, diorites, and other igneous rocks; not loose-textured, slaggy, and ashy, like the eruptive rocks of volcanoes, but compact and dense-textured, as if they had cooled under the heavy pressure of a great superincumbent load. It is only by long-continued and extensive denudation that the surface of the land can approach rocks of deep-seated origin: hence it may be concluded that the initial surface of the region stood high above the surface of the peneplain. Whenever the even sky line of the upland is spread before the observer, it should be borne in mind that the rocks now exposed to the light of day were for long ages buried in inner darkness.

Was the region, before the great denudation was accomplished, a rocky, even-topped plateau, or a rugged mountain range? Look again at the attitude of New England rocks, remembering that typical plateaus like those of Utah, New Mexico, and Arizona, have horizontal structure, while typical mountain

[1] The Kittatinny peneplain. See The Northern Appalachians, by Bailey Willis (National Geographic Monographs, No. 6, p. 187).

[2] The full discussion of this problem in its application to New England has not yet been undertaken. Along the southern border of the upland, a number of rivers that enter Long Island Sound seem to exhibit a rather marked indifference to structure, from which the origin of the upland, or at least of that part of the upland, as a submarine platform, might be argued. But it may be answered that this indifference of streams to structure can be explained by superposition through the former inland extension of the Cretaceous strata now seen in Long Island; and that the Cretaceous sea may have gained access to the region passively by the submergence of a previously denuded peneplain, as well as actively by cutting its way inland during the production of a platform. No certain settlement of this involved question can be given at present.

ranges like the Alps and Himalayas are regions of deformed structure. Ancient New England certainly belonged to the latter class. The disorderly and steeply inclined rock masses may be seen at a hundred points on hilltops and valley sides, in stream beds, railroad cuts, and quarries. The valleys of the Housatonic, Farmington, Westfield, and Deerfield rivers all expose deep sections in the western upland. Extensive quarries, such as those of Monson in the upland east of Springfield, are well worth visiting for the plain views that they afford of rock structure and attitude. The headlands of the coast frequently expose clean-swept ledges, where the deformed rocks can be admirably studied. They all teach the lesson of severe disturbance, as different as possible from the placidity that prevails among the ancient sedimentary strata of the Ohio Valley, where layer lies on layer in almost undisturbed horizontal position.

The New England rocks are not only deformed in mass: they exhibit also at many places the minute internal deformities so characteristic of regions that have been crushed under a great overlying load, and so prevalent in regions that are mountainous to-day. On Hoosac Mountain there is an old pudding stone or conglomerate whose once round pebbles are now drawn out into strips, the rock assuming the character of a gneiss. Among the Berkshire Hills ancient slates are gnarled and crinkled into schists. At many points cleavage is more or less perfectly developed in the finer-grained rocks.

The crushing forces that caused the greater and smaller deformities cannot have been exerted after the peneplain was produced, for in that event they would have deformed the upland surface. The deformation of New England must have taken place before the great denudation. During the period of most energetic deformation, New England must have had as thoroughly a mountainous form as it still has a mountainous structure. Indeed, the most probable conclusion that can be reached regarding the ancient topography of the region raises its peaks to truly Alpine heights, clothes their upper slopes with snow fields, and fills their valleys with glaciers; and all these features should be restored in the pictures that the attentive observer mentally sketches in his effort to represent the ancestry of the upland. Very slowly were the ancient mountains raised; much more slowly were they worn down, until now only their base remains. New England is a worn-out mountain range.

The Peneplain in Geographical Study.—It is worth while to stop our interrogative reflections here for a few moments to note the effect of this interpretation of the New England upland on the usual consideration of mountains in our geographical text-books. It is customary to treat mountains empirically as fixed geographical forms, permanently set upon the earth's surface. Such terms as *old mountains*, or *worn-out mountains*, are seldom employed: the regions where these terms would be appropriate are vaguely described as hilly districts, with no sufficient indication of their associated features. As a result, the scholar gathers no understanding of the nature of a region like New England; for the characteristics by which its hills are distinguished from hills of other kinds, like those of the dissected portions of our Southern coastal plain, are not clearly set before him. The empirical treatment of geography ordinarily adopted may be compared to an irrational system of botany that would place sprouting acorns, full-grown oaks, and decayed oak stumps under different species. This is so manifestly absurd that it seems to have no relation to the existing methods in geography, and yet it is a very fair illustration of them. The young ridges of southern Oregon, hardly altered by denudation from the constructional forms given by dislocation and upheaval; the vigorous Alps, long and severely deformed, and now deeply trenched by adolescent valleys; the old mountains of New England, long and severely deformed, and now broadly denuded till only their bases remain,—these three examples of mountain form may be fairly likened to the sprouting acorn, the mature oak, and the decayed oak stump; and yet it is not the fashion to emphasize these rational relationships in the ordinary method of teaching geography. Geography still retains too much of its old-fashioned, irrational methods: it has not kept pace with the advance made by geology. In spite of what the geologist has learned about the evolution of geographical forms, the geographer still too generally treats them empirically, and thus loses acquaintance with one of the most interesting phases of his subject.

The New England upland, recognized as a worn-down mountain region,—a peneplain,—soon comes to have value as a typical example of this kind of geographical form; and every such addition to the geographer's stock of types increases his appreciation of geography. In the beginning of elementary geography only a few simple types are described; but, as the work advances,

more complicated types should be introduced, otherwise the subject will always remain in a childish stage. Rivers are early taught by the description of some average, mature example; but in later years rivers of many kinds and in many stages of development should become familiar. Coast lines are at first taught simply as the margin of the land; but afterwards they may be elaborately subdivided and classified according to their origin and evolution. So with mountains: a good vigorous mountain range, shown in pictures and described in narrative form rather than in terse definition, properly introduces this large geographical family to young scholars; but later on, many kinds of mountains must be recognized, young and old, as well as mature; and of old mountains no better example can be found than familiar New England. More will be said, later on, of this important matter of equipping the student of geography with a good assortment of type forms; but we must now return to matter more immediately in hand.

The Monadnocks.—In spite of all that has been written, it is still natural that the idea of wearing down a great mountain range should be accepted rather slowly. It is difficult to believe that all the hardest mountain nuclei can waste away. Some unconsumed remnants of the ancient mountains of New England are naturally looked for, and they are no sooner looked for than found. There is hardly any comprehensive view of the upland that does not reveal a few hills surmounting the sky line by some small measure of height; and in certain places the remnants still preserve a commanding elevation. One of the best points of view in New England for the exhibition of the even upland and the occasional remnant mountains that rise above it is Massamet, or Bald Mountain, near Shelburne Falls, in northwestern Massachusetts.[1] To the eastward, beyond the Connecticut Valley, the sky line of the upland forms a horizon almost as even as that of the ocean; but beyond in the hazy distance rises the blue dome of Wachusett, an isolated eminence. Still more striking is the beautiful cone of Monadnock in the northeast, truly of no great

[1] The people of this manufacturing town on the Deerfield River have laid out an excellent path up the hillside, through the woods, to a high tower built on the summit, from which a broad prospect, uninterrupted by trees, is opened on all sides. The round trip from the railroad station may be made on foot comfortably in four hours,—an hour and a half for ascent; the same time on the tower, map in hand, studying the view; and an hour for descent. Much of the pathway is shaded. The morning hours are best for the walk.

height among the mountains of the world, yet here imposing from the strength with which its solitary pile emphasizes the evenness of the upland that it surmounts. It might well be mistaken for a volcano, so symmetrical are its slopes as seen from Massamet; but, far from having been heaped up on a once level upland, Monadnock and its fellows are the last remaining hard-rock kernels of once much higher mountain masses, now nearly worn away.

There are not many Monadnocks in southern New England: the rolling upland is seldom dominated by any strong summits.

FIG. 3.—Monadnock, from near Keene, N. H.
(*Photographed by J. A. French.*)

The view from Great Hill, near Cobalt, Conn., already mentioned, discloses no remnant mountains distinctly interrupting the upland sky line. Durfee Hill, in north-central Rhode Island, is the highest Monadnock of that State. The Ladd Observatory, on one of the hills of Providence, commands an excellent view of the upland sky line beyond the Rhode Island boundary in southeastern Massachusetts. Only one little hill in the distance distinctly surmounts the upland level, yet the sharp departure of the hill from the rule of the view attracts to it an amount of attention that is quite out of proportion to its small size. Blue Hill, a short distance south of Boston, is the most striking Monadnock east of Worcester and south of the New Hampshire line, the upland in its neighborhood being well displayed in the hilltops above

Dedham. But on passing northward into Vermont, New Hampshire, and Maine, Monadnocks are common. The White Mountains seem to be only a cluster of unconsumed remnants; the scattered mountains of northern Maine are probably of the same kind; the divide between Connecticut and Champlain drainage in Vermont appears to lie on the northern extension of the western upland of Massachusetts; and the peaks of the Green Mountains are presumably Monadnocks, like Greylock and Mount Everett farther south. But, in spite of the nearness of these northern States, they have not been explored with the upland peneplain and the Monadnocks in mind. No definite statement can at present be given as to the altitude of the upland in northern New England, or as to the degree of perfection that it attained. The region invites careful investigation.

The summits of the Monadnocks offer extended views over the upland, and they should be utilized as far as possible in teaching. An excursion to the top of Wachusett, for example, is easily accomplished from a number of cities and towns in its neighborhood, and may be made extremely profitable to a class of young scholars. But just as we should, for the time being, assume the mental and moral attitude of a people if we would truly appreciate their history, so we should stand near the level of the upland, and not at that of a Monadnock above it or of a valley below it, if we would truly appreciate it as a peneplain. Mounds that rise but little over their surroundings, like Massamet near Shelburne Falls, or Great Hill near Cobalt, hardly deserving to be called Monadnocks, offer the best opportunity for recognition of the real features of the upland.

THE VALLEYS IN THE UPLAND.

THE SLANTING ELEVATION OF THE PENEPLAIN.— The most important reflection suggested by the view of the upland peneplain of southern New England is yet to be stated, although it can hardly have escaped the attention of the reader. The peneplain has been accounted for as a surface of denudation, worn down about as low as is possible by the processes of subaërial denudation; reduced to a comparatively smooth lowland of faint relief, close to the level of the sea. Yet it is now a slanting upland rising distinctly above sea level, and its surface is no longer even and continuous, but is dissected by numerous valleys. In

the latest stage of the development of the peneplain, the rivers must have flowed on broad flood plains, adjoined by gently rolling low country on either side, here and there surmounted by some surviving Monadnock. The very facts that the peneplain is now slanting upland, not a lowland, and that it is strongly dissected by many valleys, at once suggest that it has been bodily elevated from its former to its present altitude so as to slant gently to the south and southeast; and that in consequence of this elevation the rivers that were powerless to cut their channels any deeper while the region was still a lowland have been revived into a new cycle of activity now that the region has become an upland. Only in this way can the dissection of the upland be accounted for. How the uplift was caused, or why it came at one time rather than another, no one knows. There is nothing to suggest that volcanic action had anything whatever to do with it. There is nothing to suggest that it was violent or rapid, or attended by notable tremors or earthquakes. It can only be said, that, after a long time of comparative quiet, further smoothing of the peneplain was prevented by the occurrence of an uplift of unknown origin. The general date of the uplift can be given in geological chronology; but it is sufficient here, if any one asks when the uplift occurred, to say, "It must have been long enough ago for the valleys to have been worn out since." That is a good geographical answer.

It is particularly important to recognize that the evidence leading to the belief in the uplift of the old peneplain is found entirely in the form of the region itself. It is not a conclusion based on the evidence of uplifted strata bearing marine fossils; for, while such fossiliferous strata occur both of ancient and modern dates, they do not bear on this part of our problem.[1] The uplift is known to have occurred simply because the process

[1] For example, among the deformed rocks of the upland there are ancient fossiliferous strata at various points. Certainly their fossils show that they have been uplifted with respect to the sea in which they were deposited; but, if it were not for the evidence found in the form of the dissected peneplain, it might be supposed that their present altitude above sea level had been given once for all, with the deformation of the ancient mountains, and that these fossil-bearing rocks still stand above sea level only because they have not yet been worn down from the height originally given to them. Indeed, this opinion was very generally though rather vaguely held until fifteen or twenty years ago. The adoption of the opinion now prevalent is entirely due to the recognition of the evidence based on the form of the peneplain. The first explicit application of this evidence to the case of New England was, I believe, made by Professor B. K. Emerson, of Amherst College.

of production of the peneplain demands that the region stood lower than now while the great denudation was in progress.

Those who have not studied geography outdoors may find some difficulty in accepting this argument. They are accustomed to saying, "Geologists tell us that so and so has happened;" but it would be a sad mistake to treat this problem in so irresponsible a manner. When a teacher comes to the problem of the right-angled triangle, he does not say, "Geometers tell us that the sum of the squares is so and so:" he proceeds to explain the demonstration. It is satisfactory to his own mind: he accepts it fully, and is willing to be held responsible for it. No teacher of geography should mention such a feature as an uplifted and dissected peneplain until she is fully convinced of its actual occurrence, and of the reality and sufficiency of the processes by which it is explained. No teacher in southern New England should say anything about the home peneplain to her scholars until she can say, not, "Geologists tell us so and so," but, for example, "You can easily understand that the old peneplain has been uplifted, for, if it had not been, no valleys could have been worn in it. A good place to see this is ——." While the teacher doubts, the scholars find her explanations "too hard." When the teacher has an easy mind, the scholars will, I am convinced, find no difficulty in following the essence of all the explanations here offered, provided they are presented very slowly, with plenty of local illustrations in the field, and plenty of time for their digestion, part by part. The explanations and illustrations ultimately leading to such problems as are here treated, should be begun in the earliest nature study, and reviewed so frequently, and with such expansion of application, that the scholar makes his way to the understanding of the dissected peneplain step by step, as naturally and easily as he walks to school.

Only after this long introduction can the study of the valleys of New England be properly undertaken. They have been laid aside from consideration for a number of pages, but now they may be taken up with good appreciation of their origin and form.

Revival of the Old Rivers.—As soon as the elevation of the region began, the old rivers, sleepily wandering over the peneplain, were awakened to the new task of cutting into the deep mass that had previously been safe below baselevel. During the period of elevation, and ever since, they have been busy at this new task. The larger rivers have now cut their channels

down to a moderate grade, and the further deepening of their valleys cannot be by a great amount as long as the land stands in its present attitude. The small branch streams still have steep courses: much deepening remains to be done in their valleys. During the trenching of the valleys to their present depth, the side slopes have wasted and the valleys have widened, so that they are now nowhere precipitous. They are not vertical-sided, like very young valleys, but have a more adolescent or mature expression. The peneplain is no longer a continuous upland surface, but is thoroughly carved into a rugged hill country. The valleys are so numerous that it requires a distinct mental effort to recognize them as merely interruptions in the real geographical unit of the region.

Depth and Breadth of the Valleys.—The valleys of the chief streams differ among themselves in two particulars,—depth and breadth. They are shallow near the coast, where the up-

Fig. 4.—Deerfield Valley, above Shelburne Falls, Mass.

land is but little above sea level; they are deep in the interior, where the upland may be a thousand or fifteen hundred feet or more above sea level. Close to the coast, our valleys are like those of Florida, where hardly any depth of cutting is allowed, because the whole State stands so near the level of the sea. In the interior the valleys are in matter of depth related to the

canyons that dissect the plateaus of Arizona. In both these cases the considerable elevation of the upland gives the streams permission to intrench themselves profoundly. Even the Grand Canyon of the Colorado is only about four times as deep as the Deerfield Valley in the view on the preceding page. The valley of the Naugatuck above Waterbury, shown in the next figure, has

FIG. 5.—Naugatuck Valley, near Waterbury, Conn.
(*Photographed by L. G. Westgate.*)

a depth of about five hundred feet. It should be noted that the second of these views, taken from the level of the upland, gives an excellent idea of the relation of the valley to the uplifted peneplain in which it is incised, while the picture of the Deerfield Valley, taken from nearer the river level, gives only the impression of being inclosed by rugged hills.

In respect to breadth, the most significant variation in the form of our valleys is controlled by the resistance of the rocks in which they are worn. Where the rocks are of great resistance to weathering, or *hard*, as we commonly express it, the valleys are still rather narrow and steep-sided; and from this it must be concluded that there has not yet been time since the uplift of the peneplain for valleys to widen greatly in rocks of this character. But where the rocks weather rapidly, or are *weak* or *soft*, as we generally phrase it, the slopes to the streams have already wasted away so much that the valleys have become wide open. The upper and lower parts of the Housatonic Valley give excellent

illustrations of the contrasted forms thus produced. The upper valley, generally called the Berkshire Valley, is broadly open along a belt of weak limestones, which have wasted away on either side to the hard rocks that inclose them on the east and west: the lower valley crosses the upland of western Connecticut, a region chiefly composed of resistant crystalline rocks, and here the side slopes are for the most part bold and steep. Indeed, here the rocks are so resistant that the river has not yet been able to cut down all of its channel to a smooth and gentle grade. In its course of 57 miles from Falls Village, where it leaves the limestone belt, to Derby, where it meets tide water, this strong stream descends 560 feet. It is on account of so great a distance over which the lower Housatonic has to cut its way across hard rocks, that its upper course, even on the weak rocks of the Berkshire Valley, is still held almost 1,000 feet above sea level.

Millers River offers another kind of illustration of the general principle by which the breadth of our valleys is governed. Its course leads westward near the northern boundary of Massachusetts for about thirty miles to its mouth in the Connecticut. On the way, the river crosses successive belts of harder and weaker crystalline rocks, trending about north and south. Where the rocks are weak, as between Athol and Orange, the valley is wide-opened; where the rocks are hard, as above Athol and below Orange, especially the latter, the valley is much narrower. Southward from Athol, towards Brookfield and Palmer, the peneplain is much dissected by valleys that follow the belts of weaker rocks; and, instead of resembling a continuous plateau, the upland consists of a number of dissevered hills. One of the sharpest, most isolated of these hills is seen just north of Palmer, from the trains of the Boston and Albany Railroad, foreshadowing what the rest of the upland may be reduced to when the present cycle of denudation is further advanced.

East of Worcester there are so many belts of weak rocks that the upland is greatly interrupted by broad valley lowlands; so much so, indeed, that the geographer who is just beginning his outdoor studies may think that the eyes of faith are needed hereabouts to recognize the upland remnants. The lowland of the Boston basin is one of these broad interruptions; but along its northern border the upland may be seen with some distinctness. The lowland around Narragansett Bay is another and even greater interruption, but the even sky line of the upland is

easily recognized on the east and west. The rocks of these lowlands are, indeed, so weak that they are already almost reduced to the present sea level, thus forming local peneplains of a second generation. If one's studies were limited to these much-denuded districts, it would be very difficult to decipher their history; but coming upon them from farther west, where the upland peneplain is much better preserved, and projecting its descending plane into the denuded districts, their relation to the general upland is perceived without difficulty. No explanation of their evolution seems so fitting as the one here suggested.

THE CONNECTICUT VALLEY LOWLAND.—The finest of the lowlands by which the upland is broken is that of the Connecticut Valley. Here a belt of weak red sandstones and shales, extending from the northern border of Massachusetts southward to New Haven, has been for the most part worn down to a rolling lowland, five or ten miles wide near its extremities, and fifteen or eighteen miles wide about its middle. The uplifted peneplain, once evenly continuous across the sandstone belt, is now divided by the sandstone trough into eastern and western portions, which have much the aspect of rugged plateaus when viewed from some of the occasional hills that surmount the valley lowland. The lowland has the appearance of a long, deep, broad trough when seen from the margin of the eastern or western upland.

Although called the Connecticut Valley, this beautiful lowland really consists of the wide-open confluent valleys of a number of streams, of which the Connecticut is the master. The breadth of the lowland depends, not on the size of the Connecticut, but on the weakness of the rocks on which it is opened. This is particularly well shown by following the river through the lowland across Massachusetts and into the State of Connecticut. There the lowland continues southward to the Sound; but the river turns eastward at Middletown, and enters a narrow valley in the eastern upland. Manifestly, then, it is the weakness of the sandstones and shales, and not the size of the Connecticut River, that has determined the breadth of the lowland. There are few places where this important relation is better shown.

Of all the local peneplains of the second generation in New England, the Connecticut Valley lowland is the best developed. When viewed from the margin of the upland, east or west, the smaller inequalities of its broad floor sink out of sight, and it seems to be truly a plain of completed denudation. At

the northern border of Connecticut, where the uplands have a height of about eight hundred feet, the lowland hardly averages a hundred feet above the sea. Near the northern border of Massachusetts the uplands rise to twelve or fourteen hundred feet, but the lowland hardly reaches two hundred feet. One of the most important lessons to be learned from this is the remarkable contrast in the rate of weathering and wasting of the crystalline rocks that still retain the upland form, and of the red sandstones and shales which are already worn down to a lowland. Hand specimens of the two kinds of rock readily declare a difference in their hardness. The stonecutters who dress the blocks of Monson gneiss and Longmeadow sandstone, so often used in architectural combination in recent years, will testify emphatically as to which rock is the more resistant; yet it would hardly be expected, after the most careful artificial tests, that the long-continued natural test of weathering would have discovered so great a contrast in resistance as is indicated by the form of the areas occupied by the two rocks. One still stands boldly up close to the height which both gained when the peneplain was uplifted, but from which the other has, as it were, melted away under the rays of the sun.

The same lesson is enforced when the observer stands on one of the upland hills near Middletown, and sees on the west the broad valley lowland, and on the southeast the steep-sided valley through which the lowland is drained. While the narrow outlet valley of the Connecticut has opened by wasting in the hard rock area only to its present restricted breadth, all the extensive valley lowland has been worn out. With the exception of the small part of the lowland that discharges to the Sound at New Haven, all the rock waste from the broad belt of sandstones and shales has been carried down the narrow valley to the sea. This is the best example in New England of the general relation between open longitudinal and narrow transverse valleys. The natural prepossession in such a case is that the broad valley lowland is older than the narrow outlet valley; and hence arise the mistaken explanations of the outlet as a "fracture due to some convulsion of nature," or as the "channel carved by the overflow of a lake" that is conveniently assumed to have for a time filled the lowland. These erroneous ideas have a wide acceptance among teachers at present, although there is no shadow of evidence to support them in such an example as the

one here under discussion. It is true that the broad lowland is older than the narrow outlet valley in topographic expression, but they are of the same absolute age, measured in centuries. The lowland was not made before the outlet, but only at equal pace with it. Both are excavations in the uplifted peneplain. The excavation of both began at the time of the uplift. The deepening of the downstream outlet controlled the deepening of the upstream lowland; for this relation always obtains between the downstream and the upstream portions of a river. It is in breadth, not in age or depth, that the valley lowland and the outlet valley are unlike, and it is plain that the matter of breadth is entirely controlled by the nature of the rocks in which the valleys are excavated. With so excellent an illustration of this principle as the Connecticut affords, it is to be hoped that its true explanation may soon be introduced in our elementary teaching.

The relation of the longitudinal and transverse valleys is shown again in the long Berkshire limestone valley and its transverse outlet by the lower Housatonic, as already mentioned; but this is less conspicuous than the case of the Connecticut. The latter is, however, overshadowed by the Hudson, which drains a part of the great Appalachian Valley through the deep gorge in the Highlands. The same relation is exhibited by the Delaware, the Susquehanna, the Potomac, and the James, as well as by innumerable smaller Appalachian streams, that drain open inner longitudinal valleys through narrow transverse gorges or *water gaps*. All the rock waste of the open inner valleys has been carried out through the narrow gorges. Nothing less than the sight of one of these examples will do justice to the important lesson that they teach.

The Lava Ridges of the Connecticut Valley Lowland.— Recall for a moment the Monadnocks that stand over the uplands like monuments of departed mountains. Their occurrence should lead us to expect that residual eminences might occur on the local peneplains of the second generation. Such younger Monadnocks are, in fact, abundant. The Boston basin counts them by the score, especially in the area of the Roxbury pudding stone; but the best examples of these residuals occur within the Connecticut Valley lowland, and some of these are of particular interest from their relation to the ancient volcanic history of the region.

Long ago—long before the peneplain of to-day was made, uplifted, and dissected—the red sandstones and shales were ac-

cumulated in a trough or estuary between eastern and western highlands. It was during the deposition of these strata that the famous "bird tracks" — really reptilian tracks — were made upon successive layers of muddy sand. The museum of Amherst College contains an extraordinary collection of them. For the geographer, the floods of lava or *trap* that were at several times poured out over the sandstone strata, and afterwards buried by later deposits, are more important. The molten lava spread over the even floor of the muddy estuary in broad sheets, many miles in length and breadth, and from one to four hundred feet in thickness. Some dikes and sheets of lava were driven in among the sandstone beneath the surface. At last the further accumulation of deposits in the estuary was stopped by the disturbance that gave the peculiar tilted and broken structure to the belt of red sandstones; and then it was that long-continued denudation produced the peneplain that has been our chief theme, leveling off the crystalline highlands east and west, as well as the upturned and dislocated blocks of sandstones, shales, and lavas. It would require a special monograph to do justice to the particular structures of this interesting region. Let it now suffice to restore the picture of the evenly denuded surface of the sandstone belt as a part of the old peneplain between the less smoothly denuded areas of crystalline rocks on the east and west. The sandstone beds generally dip underground eastward, and among them are the various sheets of lava, much dislocated. Now, when the further smoothing of the peneplain was stopped by the slanting uplift of the region, the sandstones and shales wasted away with comparative rapidity; but the trap sheets and dikes resisted erosion strongly, and soon came to have a distinct relief above the wasting sedimentary beds. Even when the latter are reduced to the open lowland form that they have to-day, the heavier sheets and thicker dikes of trap retain a great part of the height to which they were uplifted, thus simulating the behavior of the hard gneisses and schists of the upland.

As the lava sheets dip eastward with the sandstones, the western face of the ridges exposes bold outcropping ledges, descending precipitously to long talus slopes of loose rocky waste, which covers the underlying sandstone beds; while the eastern or back slope of the ridges descends more gradually with the slant of the lava sheets, and the next overlying sandstone beds are found only near the foot of the slope. Mount Tom, near

Northampton, Mass., and the Hanging Hills, near Meriden, Conn., are among the finest examples of these trap ridges. From their summits one may look evenly across to the uplands on the east and west, appreciating the plateau-like smoothness of their hill-tops; one may survey the broad valley lowland beneath, with its patchwork of field and woodland, and its many villages. Various

FIG. 6.—South Mountain, Hanging Hills, Meriden, Conn.
(*Photographed by W.H. C. Pynchon.*)

other ridges belong to the same range, and are, indeed, the out-cropping edges of the same lava sheet; the various notches or gaps by which the individual mountains are separated being due to dislocations of the sheet made at the time when the sandstones and the included lava beds were tilted. Mount Holyoke and Mount Tom, on the north; Talcott Mountain, west of Hartford; the Hanging Hills, Lamentation and Higby mountains, near Meriden; and Totoket and Pond (Saltonstall) mountains, east of New Haven,—are conspicuous members of the series, and are all parts of a single lava bed.

East and West rocks, near New Haven, and the long northern continuation of the latter to Gaylord Mountain, are the chief

examples of ridges formed on intrusive lava sheets; these having been driven in between the sandstone beds, instead of being poured out over their surface. Mount Carmel and the Blue Hills, southwest of Wallingford, have a peculiar interest from marking the site of great dikes or *necks* of lava. In all probability they are the *roots* of the volcano or volcanoes from which the lava sheets of the Meriden district were erupted. Similar but smaller necks have been found on the southern side of Mount Holyoke range in Massachusetts. Occasionally the lowland is surmounted by ridges of resistant sandstone (as Deerfield Mountain and the Sugar Loaves, above Northampton) or of conglomerate (as Mount Toby, north of Amherst), but these are seldom conspicuous.

The Berkshire Valley is also varied by a number of isolated hills or mountains. Here they consist of resistant schists that stand above the limestone floor. Greylock is the chief of these; for its summit not only rises above the Berkshire Valley, but dominates the upland levels on the east and west as well, reaching the greatest altitude of any mountain in Massachusetts. Smaller and lower residuals are seen south of Pittsfield, where they contribute largely to the attraction of the picturesque district about Stockbridge and Great Barrington. Bear Mountain, in the extreme northwestern part of Connecticut, the highest summit in the State, may be, for our purposes, likened to Greylock.

On any of the higher trap ridges in the Connecticut Valley, the lesson of rapid and slow wasting of weak and hard rocks may be reviewed to advantage. The meaning of the geographical forms there displayed gradually becomes so distinct that we need not say, "The lava sheets are harder than the sandstones, and hence the lava stands up in ridges, while the sandstones have been worn down to a lowland," but, "The lava sheets stand up in ridges, while the sandstones occupy the lowland: hence the lava must be much harder than the sandstones." The ridges do not owe their height above the lowland to any local uplift, but simply to retaining, in virtue of their hardness, much of the height which the weaker sandstones have lost. Where relations of this sort are clearly appreciated by geographers, it will require no argument to persuade them that the processes and results of land sculpture should form an essential part of geographical training.

Distribution of Population.—It has already been stated that the valleys and lowlands are the seats of the greatest part

of our population, while the uplands are sparsely occupied. The full reason for this will not be perceived until the relation of valleys to bays and harbors, and the origin of the water powers of the valley streams, are explained; but the broad fact is easily appreciated. Look, for example, at the western upland in contrast with the Berkshire and the Connecticut valleys west and east of it. On the upland itself there are quiet, out-of-the-way hill towns, like Savoy, Florida, Peru, Monterey. It is through these hill towns that the pedestrian should plan his excursion, if he would escape from the bustle of the world beneath, and find still preserved the quiet old New England ways. It is a district of small-field farming, too rugged for general cultivation. The patches of timber land supply wood for small local industries in the villages, and pulp for paper mills in the valleys; but to gain a living there is harder work than New Englanders even have cared to face, and they have either descended to the growing manufacturing towns at lower levels, or they have moved out West to prairies and plains. Abandoned farmhouses on the side roads tell the story with something of a dreary intonation,—the garden patches lost in weeds, the apple orchards gone to waste, the pasture lots overgrown with bushes and briers.

The narrow valleys within the upland have thriving villages, connected with the rest of the world by railroad lines. Here the farmers from the upland come down to trade; here manufacturing industries are established in great variety,—cutlery works and shoe-peg shops at Shelburne Falls in the Deerfield Valley, emery works at Chester in the Westfield Valley; while nearer the great market of New York City, along the Farmington and Naugatuck valleys in the western upland of Connecticut, hardware, tools, clocks and watches, and brass goods of every description, are produced. It would lead into the debatable ground between geography and history to recount the causes that have determined the growth of these manifold industries. Suffice it for the present to note that they are strictly limited to the valleys.

Emerging from the narrow valleys to the more open valleys, we find, on the west, North Adams, with cotton and woolen mills, and boot and shoe shops; Williamstown, with its college; Pittsfield, with varied manufactures and an active trade with the surrounding agricultural region; Dalton and Hinsdale, with great paper mills, in a side valley descending from the hills on the east side of the limestone belt. On the eastern side of the Berkshire

plateau the contrast is much stronger between the rugged upland and open lowland; for the Connecticut Valley lowland is longer, broader, and lower than the Berkshire Valley. Its smooth fields tempted early settlement from the Colony of Massachusetts Bay. Many populous cities and towns are built upon it; railroads traverse it lengthwise and crosswise; manufactures thrive; schools and colleges not only educate the youth of the valley, but attract boys and girls from the upland, and young men and young women from all over the country; products suggestive of a mild climate, such as tobacco and peaches, come from the valley farms; garden seeds are raised as an important article of trade. And all the unlikeness of the lowland to the upland is because the rocks of the one have wasted away, while those of the other have, comparatively speaking, held fast. This is the impressive lesson of the dependence of the manner of life on the sculpture of the land, that our geographies should teach.

Near the coast, where the contrast between upland and lowland is less marked than in the interior, the control exercised by the form of the land on the distribution of population and industries is not so striking as farther inland, but it may generally be perceived in a greater or less degree. Nearly all the suburban cities and towns around Boston are on the floor of the basin. The upland of the Middlesex Fells and the Monadnock-like Blue Hills are reserved as wooded public parks. The numerous manufacturing villages of eastern Massachusetts and of Rhode Island are on comparatively low ground; Marlboro and Spencer (shoe towns), and Gardner and Templeton (chair towns), being almost the only exceptions to this prevailing rule.

REVIEW.

A paragraph may be given to reviewing what has been thus far explained. The upland of southern New England serves us as the type of a peneplain, now uplifted and well advanced in a second cycle of denudation. Monadnock is a standard example of a residual mountain that rose above the peneplain when it was still a lowland, and that continues to dominate the peneplain now that it has become an upland. The Deerfield Valley exhibits a moderate advance of the processes of dissection that will in time reduce even the hard-rock upland to a lowland. The Connecticut Valley lowland is a typical example of a local peneplain

of the second generation, already developed on a belt of weak rocks, and inclosed by the adjoining hard-rock upland. Mount Tom is an admirable illustration of a residual mountain of the second generation, bearing the same relation to the valley lowland as that which Monadnock bears to the general upland. In Virginia, residual mountains of this later generation have been called *Catoctins*, taking the name of one of them to represent the class; and when our isolated hills come to be recognized as remnants surmounting the earlier or the later peneplain, the two terms *Monadnocks* and *Catoctins* may be employed to designate the members of the older and younger families.

Another paragraph may be allowed to cautioning the reader against forming too rigid and artificial conceptions of the natural processes here referred to. It must not be thought that the land stood absolutely still during all the long period of erosion by which the peneplain of the uplands was produced. Many oscillations of level probably took place, during which erosion was hastened or retarded. All that the occurrence of the peneplain demands is, that the oscillations of level were not of great measure, and that the average stand of the land remained close to the level of the peneplain for a long time. Again, it must not be thought that the erosion, by which the very ancient mountains were laid low and the peneplain of the upland was produced, was all accomplished during one uninterrupted cycle of destructive work. During the wasting of the ancient mountains, the land may have had several successive cycles of erosion, separated by uplifts and deformations of greater or less value. In each of these cycles the surface of the land may have been worn down more or less completely to the appropriate baselevel. Hence we are probably in error when speaking of the local peneplains of the valley lowlands as belonging to a *second* generation, and thus implying that the peneplain of the upland was of the *first* generation. The upland peneplain is truly the oldest that has yet been clearly recognized; but perhaps, when the sculpture of the White Mountains and of the Adirondacks is carefully studied, still older and higher peneplains may be discovered, as they have already been in the highlands of North Carolina. Caution would therefore suggest that the peneplain of our upland be referred to, in algebraic terms, as of the nth generation; the local peneplain of the lowlands would then be of the $(n + 1)$th generation. Still further, it must not be imagined that the

greater deformation by which the ancient mountains were produced was the result of a single period of disturbance: various successive efforts of crushing and breaking the crust of the earth probably occurred, and at some undefined time between the first crushing and final wearing down to the peneplain level the ancient mountains gained their greatest height. It may be noted, however, that the latest serious deformation of the New England region was the one by which the sandstones and lava sheets of the Connecticut Valley belt were tilted and broken. The slanting uplift of the peneplain to the upland altitude seems to have been accomplished without perceptible breaking, and with only a slight warping.

THE GLACIAL INVASION.

The limits of this monograph prevent more than a brief consideration of two remaining subjects,—the glacial invasion, by means of which many characteristic geographical details were determined; and the associated depression of the land, as a result of which the lower parts of many valleys were changed into bays. Hence we must proceed more rapidly to direct assertion.

Various Forms assumed by Glacial Drift.—Just as Greenland is now ice-covered, so was New England once ice-covered after the general features of upland and valley had been developed. The ice sheet was thick enough to bury our Monadnocks. It crept slowly down the general slope of the upland to the south and southeast; it scraped along all the loose soil that it found ready made, it plucked many a bowlder from projecting ledges, and it wore down the rock surface somewhat lower than it had been; it was presumably more active in deepening the soft-rock valleys than in rubbing down the hard-rock hills. If the ice sheet had lasted a very long time, or acted with very great energy, it might have left the rocky floor of New England clean-swept and bare; but as a fact the greater part of the plunder that it had gathered was dragged along for only a moderate distance, and now lies spread irregularly over our province as a sheet of *drift*. The lowest member of the drift, lying directly on the scored rock surface, is an unstratified, compact mixture of all manner of materials, coarse and fine; this is called *bowlder clay* or *till*. Its surface is generally smoothly rolling. Here bare ledges protrude through it; there its thickness

locally increases, so that it assumes the form of rounded hills, called *drumlins*, averaging half a mile in length and toward two hundred feet in height. Many of these may be seen on the upland between Spencer, Mass., and Pomfret, Conn. They occur in lowlands also, as on the floor of Boston basin and on the Connecticut Valley lowland about Durham. So much of the drift as was dragged, carried, or washed along to the farthest margin of the ice sheet formed there a series of uneven hills inclosing many

FIG. 7.—Drumlin, Groton, Mass.
(*Photographed by G. H. Barton.*)

an undrained hollow among them, and fronted by a plain of washed sand and gravel spread forward by the escaping ice water. Hill ranges of this kind are called *terminal moraines*. Rhode Island possesses an excellent example near its southern coast, west of Point Judith. Southward from Plymouth, Mass., morainic hills may be traced far around the curve of Cape Cod. As the ice sheet was finally melting away, much gravel, sand, and clay were washed forward from its irregularly retreating edge, and lodged in valleys and lowlands, sometimes taking the shape of gravel ridges, formed in tunnels under the ice near its margin, and then named *eskers*, like the so-called "Indian Ridges" at Andover, Mass.; sometimes accumulating in sand and gravel mounds, formed in cavities close to the ice edge, and then called

kames; sometimes spread out in smooth flood plains, especially along the larger stream courses, but now partly washed away, and thus forming our well-known *river terraces.* The irregular distribution of the drift has obstructed many valleys, and thus formed our numerous lakes and ponds. The streams, more or less displaced from their well-graded channels of preglacial time, have here and there cut down through the drift upon buried rock ledges; and thus our rapids and falls have been produced.

Geographical Consequences of Glacial Action.—Although strictly subordinate to the stronger features of uplands, valleys, and lowlands, it is manifest that all these minor drift forms are important as geographical details, and as such they should have due consideration in our home teaching. Glacial action had no share in the evolution of Florida and Texas, and it would therefore be a comparatively irrelevant subject in Southern schools; but in New England, glacial action has been a more important factor in our geographical development than the Indians ever were in our historical development. The glacial elements in our geography have distinctly affected the course of our history from beginning to end, while the Indians were after a time pushed aside. The hills that guided the Pilgrims from Provincetown across Cape Cod Bay to Plymouth were the moraines of Manomet. The broad drift plains of the Connecticut were early sought out as places for settlement when the rugged uplands that separated them from the colonies of the eastern coast remained a wilderness; the many "fields"—Springfield, Northfield, Westfield, Greenfield, Deerfield, and the rest—all owe their surnames to the smooth drift floor of the valley lowland. The last battle of King Philip's war was fought in the marshy district to which the Indians had retreated behind the terminal moraine of southern Rhode Island. The small smelting furnaces in which iron was made in New England before the days of railroads, were supplied with bog ore that was taken from shallow glacial ponds or marshes. The lakes that often serve as reservoirs—to flood streams and wash logs down to the mills, to store water for factories, and to supply water to cities and towns—are all of glacial origin. Beacon Hill, Bunker Hill, and the hills of Somerville, on which earthworks were thrown up during the Revolutionary struggle about Boston, are all drumlins. The plentiful supply of sand and gravel that has made the filling of Boston Back Bay comparatively inexpensive has all come from kames and sand

plains a few miles up the valley of the Charles River. The water power around which so much New England capital has been invested, and about which so large a share of New England population is gathering, is all a consequence of the glacial invasion; and, although steam has in recent years been largely added to water power, it remains true that the beginning of the great industries of Fall River, Lowell, Manchester, Lewiston, Pawtucket, Waterbury, and many other places, depended strictly on the falls in the streams on which these striving cities were built. The occurrence of waterfalls not only in the small head-water streams, but also on the lower courses of the larger rivers, is peculiarly characteristic of their origin, and peculiarly important in their economic relations; for thereby the factory towns and cities often gain large volumes of water in the fall, combined with situation not far inland.

THE COAST LINE.

The Depression of the Land.—When our valleys are followed down to the sea, we find no deltas built forward by the streams, in spite of the large amount of rock waste that has been washed out from the upland during its dissection. On the contrary, before the general shore line is reached, the broadening floor of the valley is flooded with tide water, and the running river is transformed into an estuary or a bay. The simplest explanation of all this is, that, since the valleys were excavated, the region has suffered a moderate depression, whereby the upland margin is sunk below sea level, its outer hills standing up "half-seas over" as islands, while the lower ends of its valleys are drowned. The estuary of the Thames below Norwich, Conn., is as beautiful an example of a drowned valley as can be found anywhere; it should serve New Englanders for a type of the many other examples of the kind elsewhere in the world. Narragansett Bay is but the submerged part of a lowland that is otherwise in many ways comparable to the Connecticut Valley lowland. The three rivers, Pawtuxet, Blackstone, and Taunton, that once were only branches of what may be called "Narragansett River," are now converted into independent river systems by the drowning of their trunk; and here again we have a type example, in terms of which many cases in foreign lands may be easily described. The fringing islands along the coast of Maine

are the half-drowned hills that once surmounted the intervening valley floors, the latter being now submerged by long arms of the sea. Norway and Patagonia are best taught after these home illustrations are appreciated.

Modification by Waves and Currents. — Since the land and sea assumed their present relative position, the waves and the tides have effected certain significant changes in the form of the coast; and here we enter upon a subject that deserves as deliberate a treatment as has been given to our dissected peneplain. In a general way the changes along the shore tend to promote simplicity of outline: the islands are in time cut away; the headlands are cut back; and the bays are bridged across with bars, and filled with deltas and tidal marshes. Given time enough, and the irregular margin of New England would be cut back into long, smooth curves, like those of northwestern France, where the sea has made great inroads on the land; but time enough has not yet been allowed. Where our coast is rocky, it has not as yet suffered much change: the resistant headlands are not yet cut back into cliffs of notable height, and the bays are as a rule too deep yet to have been filled by deltas or inclosed by bars. But where the coast consists of glacial drift, it has already, in the present cycle of shore action, been much altered, the amount of modification depending chiefly on the openness of exposure to the strong waves of the ocean. The shore along the northern side of Buzzard's Bay is still extremely irregular, its headlands and bays hardly being changed from the outline they had when the sea first lay at its present level. The southern side of Cape Cod, somewhat protected by the outlying islands, still retains something of its original irregular outline, although its headlands are partly cut back, and its bays are bridged across, all uniting in swinging curves of greater or less radius. The southern side of Martha's Vineyard is much simpler, for here stronger waves roll along the shore, and the coast is reduced almost to a straight line; half the headlands being already consumed, and only half the bays remaining. The outer side of Nantucket seems to have suffered a still greater loss, for the headlands that once separated the little bays of its coast are now cut back so far that only the smallest remnant of the bay heads can be detected. The eastern side of Cape Cod is for the greater part a long straight cliff of clay and sand, surmounting one of the finest beaches in the world. Here no trace of the original

irregular shore line remains. When the coast line is studied carefully on the plan thus suggested,—first considering the manner in which the original coast line was determined, when the land and sea took their present relative position; then considering the changes thus far produced in the original coast line by wave and current action,—it acquires the same quality of enlivened interest that is attached to the study of the development of land forms: it becomes a subject worthy of special treatment.

Geographical Consequences of Coastal Form.—Some of our coasts are almost uninhabited, because they have no harborage; for example, the matured cliff coast on the "back" or east side of Cape Cod, the adolescent southern coasts of Nantucket and Martha's Vineyard, and the coast of Rhode Island west of Point Judith. The harbors among the many outer islands of the half-drowned coast of Maine have developed no large cities, because the islands are too small and too disconnected to favor the concentration of population. New Hampshire, having the smallest water boundary of any New England State, is the only exception to the rule that each State has its largest city on a harbor,—Portland, Boston, Providence, New Haven, and Burlington, all attest the rule,—and before inland manufactures were developed New Hampshire itself made no exception. All these harbor cities except Burlington have grown from early colonial settlements, in which good harborage was the chief element in determining location; but the causes which have led to the greater growth of certain harbor settlements than of others are generally to be found in some complicated relation between coast and interior; partly also in political influences, such as accompany the location of a State capital; and partly in seniority of settlement. Some cities on drowned rivers have the advantage of tide water a number of miles inland from the general coast line. Bangor, Augusta, Norwich, illustrate this relation.

CONCLUSION.

It is only after a clear perception of the forms of the land is gained by tracing out their development that the careful teacher or the serious student is prepared to undertake the discussion of the relation of geography to history. In no way so well as by modern physiographic methods are the facts of land form brought clearly before the mind. Throughout this monograph a knowledge of the development of land forms is not urged upon

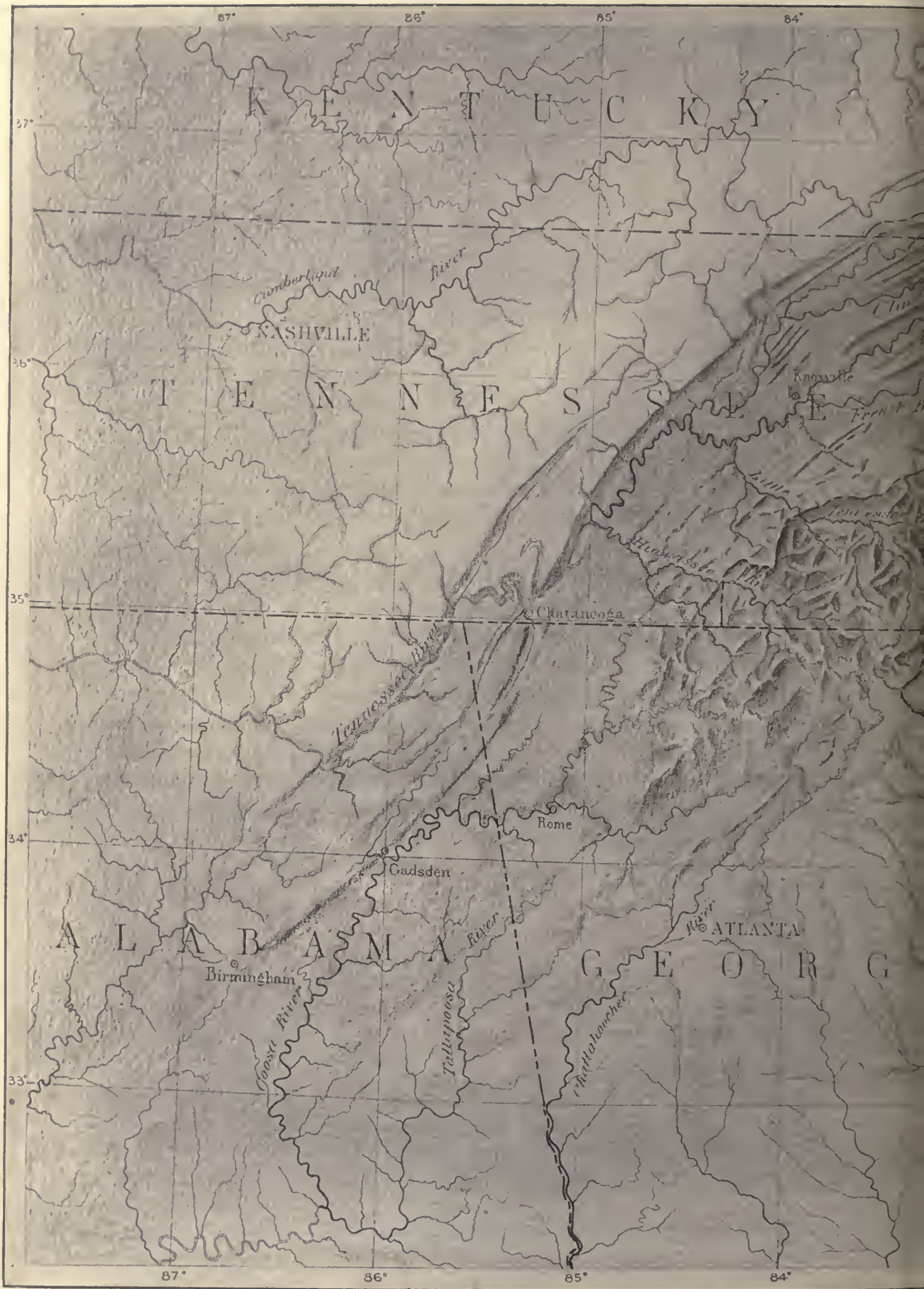
the geographer as an end in itself,—although it may truly be regarded as a worthy end of study by those who wish to devote their whole time to it,—but as the best means to another end; namely, the appreciation of the facts of land form which constitute the foundation of all thorough geographical study. It is often maintained that a devoted study of the facts themselves, without regard to their meaning or development, will suffice to place them clearly enough before the mind; but this view is contradicted both by general experience in many subjects where rational explanation has replaced empirical generalization, and by the special experience of geography as well. Left to itself as an empirical study, in which the development of land forms was hardly allowed to enter, it has languished for many years, until it became a subject for continual complaint. Gradually beginning with easy examples like sand dunes and volcanoes and deltas, simple explanations of form as a result of process were admitted. To-day it is only by those who fail to see the direction of geographical progress, and who are ignorant of the progress already gained, that objection is made against the effort to bring every geographical fact under the explanation of natural processes. No one of active mind can look across our upland and fail to gather increased pleasure and profit from understanding its history. No one who looks upon geography as the study of the earth in relation to man can contemplate the contrast between glaciated New England and non-glaciated Carolina without inquiring into the meaning of the contrast: he might as well study the Sahara and the Sudan without asking the reason for the dryness of the one and the moisture of the other. It is a mistake in this day to speak of the many islands along the coast of Maine, and not bear in mind that they result essentially from the half-drowning of the margin of the dissected upland; or to mention Narragansett Bay and the estuary of the Thames without remembering that they are only drowned valleys, one wide, the other narrow; or to contrast the rugged coast of Buzzard's Bay with the smooth outer side of Cape Cod, and fail to see that one is still young while the other is already mature. It is as much in the spirit of protest against the omission of physiographic explanations in the common-school teaching of our home geography, as in the desire to bring forward the salient physiographic features of southern New England, that this monograph has been written.

THE SOUTHERN APPALACHIANS.

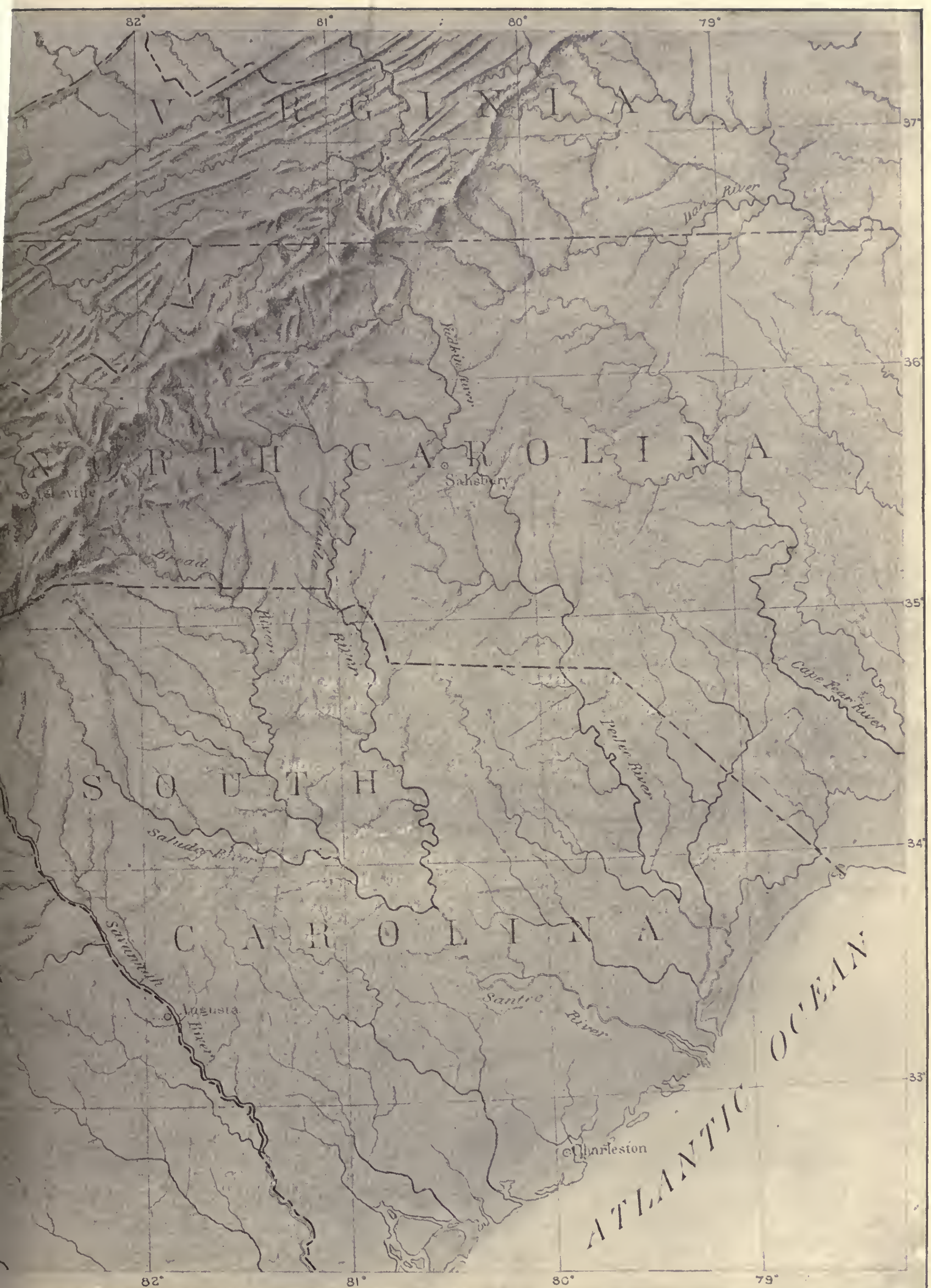
By C. Willard Hayes.

THE PROVINCE DEFINED.

Draw a line from the most easterly point of Kentucky, southeastward across Virginia and North Carolina, to Cape Fear on the Atlantic. This will form the boundary between the Northern and Southern Appalachians. In the northern division, described by Mr. Willis in Monograph No. 6, the most striking characteristic is the large number of parallel linear ridges occupying the central zone between the Blue Ridge and the Alleghany Front. Southward from the line above indicated the linear ridges decrease in number and importance; the central zone becomes a true valley, bounded on the east by a broad complex mountain belt instead of a single range, and on the west by several detached plateaus. Decided differences likewise appear in the drainage of the two divisions, as well as in the forms of relief. On the north the drainage is eastward from the Alleghany Front, the Great Appalachian Valley, and the Blue Ridge, by streams flowing directly to the Atlantic, or westward by New River to the Ohio. The line between the two divisions indicated above is approximately on the divide south of New River, beyond which no streams break through the Blue Ridge toward the east, and only one, the Tennessee, escapes from the valley zone toward the west. It thus appears that the subdivision of the Appalachians into a northern and a southern division is not arbitrary, but is based upon broad physiographic differences between the two regions. These differences will appear more prominently in the course of the detailed description of the Southern Appalachians.



87°
86°
85°
84°
37°
36°
35°
34°
33°
KENTUCKY
TENNESSEE
ALABAMA
GEORG
Cumberland River
NASHVILLE
Knoxville
Chatanooga
Tennessee River
Rome
Gadsden
Birmingham
ATLANTA
Coosa River
Tallapoosa River
Chattahoochee River



VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
ATLANTIC OCEAN
Dan River
Yadkin River
Salisbury
Asheville
Broad River
Catawba River
Cape Fear River
Pedee River
Saluda River
Savannah River
Augusta
Santee River
Charleston
82°
81°
80°
79°
37°
36°
35°
34°
33°

The Southern Appalachian Province may be more exactly defined as the region lying southwest of a line joining the easternmost point of Kentucky with Cape Fear, and limited on the southeast, south, and west by the level plains which border the Atlantic, the Gulf, and the Mississippi.

PHYSIOGRAPHIC DIVISIONS OF THE SOUTHERN APPALACHIANS.

The region thus defined is not a simple physiographic unit, but is highly complex, and may be further subdivided into five well-marked divisions, each characterized by the prevalence of a distinct type of surface. The boundaries between these natural physiographic divisions extend lengthwise of the province (that is, northeast and southwest), and they are therefore long, narrow belts, with their sides approximately parallel. Named in their order across the province from southeast to northwest, they are (1) the Piedmont Plain, (2) the Appalachian Mountains, (3) the Appalachian Valley, (4) the Cumberland Plateaus, (5) the Interior Lowlands. The location, boundaries, and chief characteristics of these five divisions will first be given, followed later by a more detailed account of the three which more strictly constitute the Southern Appalachians.

(1) The Piedmont Plain extends along the southeastern base of the Appalachian Mountains. Its surface has a gentle eastward slope from an altitude of about 1,000 feet at the western edge to 250 or 300 feet on the east, where the crystalline rocks of which it is chiefly composed pass beneath the sands and clays of the Coastal Plain. The surface is not that of a smooth plain, for the rivers and creeks flowing across it have cut deep and rather narrow channels. They have etched and roughened a surface once much smoother than now. The western limit of the Piedmont Plain through North and South Carolina and a portion of Georgia is along an irregular line, on which the gentle slope of the etched plain changes to the steep slopes of the Blue Ridge and its outliers, the eastern members of the Appalachian Mountain System. Farther south the western limit is not so well marked, for the surface of the mountain belt has been worn down almost as smooth as the plain itself.

(2) The Appalachian Mountains occupy a narrow belt which extends northeastward from eastern Alabama, and swells out to

its greatest width of about 70 miles in western North Carolina. This belt is not dominated by a single mountain range, but is occupied by numerous groups of mountains of nearly equal magnitude. To the eastern members of this complex system, disregarding a few groups of outliers to be described later, the name "Blue Ridge" is generally applied. It carries the main divide between the Atlantic and Gulf drainage southwestward from the Roanoke in Virginia, across North Carolina, to the Chattooga and Tallulah rivers in South Carolina. The southeastern slopes of the Blue Ridge are extremely steep, forming an irregular escarpment toward the Piedmont Plain. The northwestern slopes, on the other hand, are usually gentle, with slight descent to the high valleys upon that side.

The northwestern edge of the mountain belt is marked by a range somewhat higher, but less continuous, than the Blue Ridge. This is called the Unaka Range. Toward the Virginia line it merges into the Blue Ridge, and thence southwestward diverges from the latter, terminating in northern Georgia. Between these two bounding ranges is a long, narrow, triangular area characterized by high valleys, above which rise many irregular mountain masses, most of their summits reaching a common plane between 4,000 and 5,000 feet above sea level. The culminating point of the region is toward its northern end in the Black Mountains, one of which, Mitchell Peak, reaches an altitude of 6,711 feet.

(3) The Great Appalachian Valley consists of a long, narrow zone, whose surface is depressed several hundred feet below the highlands on either side. It is not a simple valley belonging to a single great river system, but is a structural belt within which the valley type of surface predominates. Its broad curves conform to the structural axes of the Appalachians; and their form, as well as the width of the valley, is quite independent of the size of the stream which occupies it. Within this belt are many elevations rising from 800 to 1,800 feet above its general level. The highest of these form a series of ridges along the southeastern side, of which Chilhowee Mountain may be regarded as the type. In other parts of the valley are long even-crested ridges, of which Clinch Mountain is the type, rising nearly to the level of the highlands on either side.

(4) The Cumberland Plateaus occupy the next belt beyond the Great Valley, their eastern escarpments rising abruptly along

its western side. They occupy a belt of country in which the plateau type predominates, extending with varying width, through eastern Kentucky and Tennessee and northern Georgia and Alabama, nearly to the Mississippi line. The belt reaches its greatest elevation in Kentucky, and has a gradual descent toward the south and west, finally merging into the Gulf Coastal Plain in central Alabama. The western limit of the belt is an extremely irregular escarpment, well marked in Alabama and Tennessee, but becoming indistinct in Kentucky.

(5) West of the Cumberland Plateaus is a broad belt of country forming a physiographic division to which no distinctive name has hitherto been applied. It extends westward to the Tennessee and Ohio rivers, embracing the central basin and its highland rim in Tennessee, and the blue-grass region and western coal field of Kentucky. This region is essentially a plain of low relief, holding the same relations to the Cumberland Plateaus that the Piedmont Plain does to the Appalachian Mountains. It is, in fact, a western Piedmont Plain. In order to avoid confusion, the region is here called the Interior Lowlands.

From the foregoing brief outline it is seen that the Southern Appalachian Province is composed of two elevated belts,—the Appalachian Mountains and the Cumberland Plateaus,—separated by a depressed zone, the Appalachian Valley; while on either side are Piedmont Plains,—the Atlantic Piedmont on the southeast, and the Ohio Piedmont or Interior Lowlands on the northwest.

THE PROBLEM AND THE FACTORS.

In order to appreciate the significance of these physiographic divisions, and to understand their origin, certain fundamental physiographic processes must be thoroughly understood. Although they have been explained at length in an earlier monograph, those that are particularly applicable to this region will be briefly reviewed. It is also important that something should be known of the geology of the region—the composition of the rocks and their structural relations—in order to understand the conditions under which the physiographic forces work: hence a very brief outline of the geology will also be given before the several divisions are described.

It must be borne in mind that everywhere on the earth's surface where there is land two grand physiographic processes are going on,—the first *diastrophism*, the elevation and depression of the land by forces acting from beneath; and the second *gradation*, the wearing-down of the land chiefly by the action of running water. Although the forces producing diastrophism have sometimes elevated and at other times depressed the surface of the Appalachian Province, the elevations have been greater than the depressions, and the resultant effect has been a gain in altitude. The process of gradation also tends in some places to build up and in others to lower the surface of the land; but the lowering has been far more common than the building up, so that, on the whole, the effects of the two processes have been in opposite directions. Diastrophism has lifted the land, and gradation has worn down its surface. At times the former process has gained upon the latter, and the region has had then a greater elevation; at others gradation has been most active, and the surface has been worn down toward sea level. Thus the present altitude of the region is due to the balance between the two grand physiographic processes, while the forms of the surface are due almost entirely to the character of the materials on which the forces of gradation are at work. Differences in the texture and structure are the principal causes of differences in the surface forms, and so of the physiographic divisions of the Appalachian Province outlined above. The amount of elevation is an important but subordinate cause of present differences of surface.

A brief examination of the way in which the process of gradation is accomplished, and some account of the character and structure of the rocks in different portions of the Southern Appalachians, will make clear the origin of its physiographic subdivisions.

Physiographic Factors.—The manner in which a river carves its valley has already been explained in a former monograph,—that on "Physiographic Processes," by Major Powell,—and need be only briefly referred to here. It was shown that when, through the action of diastrophic forces, a river finds itself flowing at a considerable altitude above the sea, its first work is to wear down its channel to near sea level by the process of *vertical corrasion;* that when this is nearly accomplished, and its fall greatly lessened, it swings from side to side in ever-widening

curves, and broadens its valley by the process of *lateral corrasion;* and that the two are accompanied by a third process, that of *erosion*, by which the general surface of the country is worn down, its steep slopes smoothed out, and the material carried to the sea. These processes, if continued sufficiently long, reduce the surface to a low, level plain,—a *base-leveled plain* if the process is nearly complete, and a *peneplain* if some inequalities remain unreduced. Naturally it is seldom that a region is found in which the process of gradation has just begun, or in which it has reached completion in the production of a perfect plain. Most portions of the earth's surface show the process in a more or less advanced stage. This is true of the Southern Appalachian region, and the forms of its surface are such as characterize various stages of the process. At each stage three factors are important in determining the details of the land surface in any region. These are (1) the character of the rocks considered with reference to their ability to resist erosion; (2) the alternation of hard and soft beds; and (3) the altitude of the beds with reference to a horizontal plane.

It is evident that soft rocks—i.e., those that are soluble (as limestone), or which crumble readily when exposed to the air (as calcareous shales)—will be worn down and carried away more rapidly than those which are composed of insoluble material, and are not affected by weathering (as quartzite and argillaceous slate). Hence, where the initial altitude is the same, areas underlain by the first class of rocks will be soonest reduced to base-level, and may form low level plains; while the areas underlain by hard rocks, although subjected to the same agencies of degradation for the same length of time, remain above base-level as mountains or hills. Again, if beds of different character alternate, as beds of limestone with beds of quartzite, the latter are more readily broken down by undermining and sapping than where the whole mass is composed of homogeneous, even though less resistant, material. Finally, if the beds are horizontal, they give a totally different form to the surface during gradation than if they are steeply inclined, especially if there is at the same time an alternation of hard and soft beds. In this case the streams first cut narrow gorges bounded by cliffs which recede as already explained, the hard beds forming the escarpments of terraces, and the intervening soft beds forming their level tops or gentle slopes. If, on the other hand, the strata are steeply

inclined, any particular hard bed quickly passes below the base-level of erosion. The soft beds are rapidly worn down to this level, while the hard bed projects as a narrow ridge or line of knobs.

While the altitude of the region, as stated above, is the resultant of the two processes elevation and gradation, the manner in which the elevation took place has exercised a controlling influence over the topographic forms. In outlining the physiographic divisions, it was stated that no dominant range overtopped its neighbors in either of the highland belts. On the contrary, in the Appalachian Mountains, where such a dominant range might be looked for, the greater number of summits reach nearly to a common plane. If the present altitude of the region had been attained during a single period of elevation, either gradual or rapid, there would be much greater diversity in the height of different portions. The altitude of any part of the surface would then represent almost exactly the product of two factors,—(1) the resistance of the material at that particular point, and (2) the nearness to main drainage lines. High points might be due to relatively soft rocks, if favorably situated far from master streams, or to hard rocks not so situated; while the highest points would result from a combination of hardest rocks and most favorable location. The absence of dominant peaks, then, taken in connection with other facts, indicates that the elevation has not been accomplished in a single period, but has consisted of a series of comparatively rapid movements, separated by long periods of rest. During the latter the forces of gradation repeatedly wore down the surface to a more or less perfect plain. The soft rocks were protected below the base-level of erosion until another uplift, while the hard rocks were reduced nearly, if not quite, to that level: hence difference of rock texture was not permitted to exercise its full influence on the relief, but was kept within certain definite limits by the formation of successive peneplains.

Geologic Factors.—The southeastern portion of the Appalachian Province—i.e., the Piedmont Plain and a part of the mountain belt—has probably been a land area since the earliest geologic periods of which we have record. The rocks are almost wholly crystalline, in part sediments which have been rendered crystalline by heat and pressure, and in part rocks which have cooled and crystallized from a molten condition. The former

are called *metamorphic*, and the latter *eruptive* rocks; but they sometimes resemble each other so closely that it is not always possible to distinguish them.

During all or the greater part of Paleozoic time the region to the northwest of the Appalachian Mountains was occupied by a sea in which sediments derived from the old land to the southeast were being deposited. When erosion of the land was rapid, by reason of its great altitude, the streams carried down coarse material, sand and gravel, which was spread over the sea bottom mostly near the shore, and now forms beds of sandstone and conglomerate. When the old land had been partly worn down, the streams carried only fine sand and mud, which was more widely distributed by waves and currents, and now appears as shale. Finally, when the surface was so far reduced that the streams became sluggish, they could carry only materials in solution, chiefly carbonates of lime and magnesia, which were deposited on the sea floor partly through the agency of animals, and partly as a chemical precipitate. Thus were formed the great beds of limestone and dolomite. All the beds thus laid down were originally nearly horizontal, though not entirely so; for some parts of the sea bottom appear to have been depressed more than others, as though by the weight of sediment heaped upon them.

Finally, near the close of Paleozoic time, the interior sea diminished in size by the emergence of much of its bottom to form dry land. At the same time, the crust of the earth contracted, so that great wrinkles rose upon its surface as they do upon a withered apple. These wrinkles were not uniformly distributed, but were confined to narrow belts along certain lines, which appear to have been lines of weakness, where the strata could be most easily bent and broken. In this manner the strata within a zone from 75 to 150 miles in width, stretching from New York to central Alabama and an unknown distance beyond, have been thrown into a series of long, narrow, parallel folds. On the southeast is the original land area from which the interior sediments were derived, its crystalline rocks forming a massive buttress against which the sediments were thrust and bent. To the northwest of the folded belt the strata stretch for many miles across the Mississippi Valley, with but little change from their original horizontal position. The subdivisions of the Appalachian Province were thus determined long before the incep-

tion of the sculpturing processes which have given to them their distinctive forms.

The mountain belt is the seaward portion of the old Paleozoic continent from which the rocks to the westward were derived; the Great Valley is the landward portion of the Paleozoic sea in which the coarse sediments were mostly deposited, and to which the subsequent folding was mostly confined; while the plateaus are composed of the offshore deposits, which retain their original horizontal position.

DESCRIPTION OF THE PHYSIOGRAPHIC DIVISIONS.

Bearing in mind the principles of physiography outlined above, and the differences in geologic structure, we are now prepared to examine more in detail the forms of relief of the various subdivisions of the Southern Appalachians, and to trace the connection between structure and topographic form. Only the two belts of highland, with the intervening valley, will be considered; the Piedmont Plain and the Interior Lowlands lying beyond the scope of this paper.

The Cumberland Plateaus.—The western of these three divisions, the Cumberland Plateau, will be taken up first, since it presents the simplest physiographic conditions. The rocks which form the surface in this region are of Carboniferous age, and consist of sandstones, shales, and limestones. The limestones lie beneath the sandstones, while the beds of shale alternate with beds of sandstone, and all the strata are nearly horizontal. The limestone is degraded chiefly by solution; while the sandstone is insoluble, and can be worn down most readily by undermining and sapping. As soon, therefore, as the streams by vertical corrasion have cut through the sandstones and shales into the underlying limestone, they are bounded by cliffs, and the degradation of the entire region is effected chiefly by their recession. The slopes are kept steep by the more rapid removal of the lower limestone than of the upper sandstone beds. The beds of sandstone form steep, often vertical edges of terraces, while the intervening beds of shale form their more or less gently sloping surfaces. It is chiefly in the central portion that the plateau character is well marked. In northern Georgia and Alabama and the adjacent portions of Tennessee the conditions are

favorable for the development and persistence of steep escarpments bounding level plateaus. Farther south the base of the sandstone is so low that the streams do not reach the limestone, and hence the process of sapping, by which the cliffs recede while retaining their steep slopes, is not favored. The same is true in eastern Kentucky and the adjacent portions of Tennessee. Also in the latter regions the sandstones are nearly homogeneous, and do not afford the strong contrasts between alternating beds which are favorable for the formation of cliffs: hence the slopes, although steep, are smooth from top to bottom, and the region is cut into hills with sharp or rounded summits.

The opposite sides of the plateau are formed by abrupt escarpments. That on the east, fronting upon the Appalachian Valley, is generally straight or broadly curved, except for a single abrupt bend which it makes north of the Emory River. Here the escarpment turns from its northeast course sharply toward the northwest for a few miles, and then resumes its former direction. The western escarpment, on the other hand, is extremely irregular. Streams flowing westward from the plateau have cut deep reëntrant angles far within its edge, leaving many narrow spurs projecting into the lowland beyond. This difference between the escarpment on opposite sides of the plateau is due chiefly to the attitude of the underlying rocks. Toward the west the strata extend for a long distance nearly horizontal. The highland has been converted into lowland by erosion of the face of the escarpment by the process of cliff recession already described; and this recession has been irregular,—most rapid where the streams could bear away the débris from the base of the cliffs, and least rapid far from the larger streams, where the transporting power of the water was small: hence the deeply reëntrant coves and the strongly salient spurs. The form of the eastern escarpment, on the other hand, does not depend on the accidents of cliff recession, for the recession is controlled by the attitude of the strata. As already indicated, the region east of the plateau is characterized by steeply inclined strata. The folding which they have suffered has brought underlying soft limestones and shales high above the base-level of erosion, where they were attacked and worn away. At the present escarpment the strata dip steeply to the westward, carrying the soft rocks below the base-level, and presenting a barrier of hard rocks beyond which erosion has not yet been able to go: in other words,

the position of the escarpment depends on the position of the westernmost of the steep folds characterizing the Appalachian Valley belt.

From the Emory River southward to the Tennessee at Chattanooga, the eastern boundary of the plateau is a linear escarpment; but twelve miles to the west is a narrow valley, perfectly straight, and also bounded by parallel linear escarpments. This is Sequatchie Valley. Its position and form are directly dependent upon a narrow anticlinal fold, which extends parallel with the folds in the belt to the eastward, and which lifted the plateau sandstone so far above base-level that it was easily removed, exposing the underlying soft limestone to erosion. The process by which this linear valley was formed is still going on at the northern end of the anticline, where the arching strata are not yet wholly removed. They form the Crab Orchard Mountains, which extend northward directly in line with the Sequatchie Valley. Wherever the protecting cap of sandstone has been removed, deep coves are formed in the underlying limestone. These are often surrounded by a rim of sandstone, and the water collecting in them flows off through subterranean passages which it has formed by the solution of the limestone.

From the southern border of Tennessee, southward well into Alabama, the plateau is separated into three or more narrow strips by parallel anticlinal valleys, one of them the continuation of Sequatchie Valley, and the others formed in exactly the same manner. The easternmost of these narrow plateaus is Lookout Mountain, which terminates in a high abrupt point at Chattanooga. Southward from this point the mountain widens slightly, and toward the southern end changes its form from a level-topped plateau to a shallow trough, the parallel escarpments passing into monoclinal ridges, which terminate abruptly in Alabama at Gadsden and Attalla. West of Lookout Mountain, and separated from it by Lookout and Wills valleys, is Sand Mountain, the southward continuation of Walden Plateau, and, like it, bounded by parallel linear escarpments. Beyond Sand Mountain is the Cumberland Plateau proper, in northern Alabama, so deeply dissected that only isolated mesas remain, but south of the Tennessee River forming a broad table-land sloping gently southward.

The Appalachian Valley.—As already stated, the Great Appalachian Valley is located upon a belt of intensely folded strata,

and to the structure and character of the rocks it directly owes its characteristic features. Its several portions are occupied by distinct river systems, and the position and form of the valley are independent of the position and size of the streams it bears. The valley has a width of about 45 miles in northern Georgia and Alabama, 50 miles opposite the broadest portion of the Appalachian Mountains, expanding to 65 miles in northern Tennessee, and contracting to 30 miles in southern Virginia. The western side of the valley is formed by the plateau escarpment rising abruptly from 800 to 1,500 feet, its summit everywhere presenting an almost perfectly straight horizon. East of the Great Valley rise the Unakas, their sharp or rounded summits forming a sky line totally different from that to the west.

To one traversing this region by rail its true character is not apparent. He sees innumerable hills and ridges of varying heights inclosing broad or narrow valleys, according to the size of the stream. The limiting highlands are generally hidden by the nearer elevations, and it is seldom that both can be seen at the same time. If, however, the observer ascends to the highland on either side, the hills and ridges which give character to the country as seen from below appear only as minor inequalities of the surface. The region is essentially a broad plain within whose surfaces the streams have carved their valleys from 50 to 300 feet.

The ridges which occur in various portions of the valley belt may be classified in three groups. In the first are those which approach in altitude the plateau escarpments and the high valleys of the Appalachian Mountains. To this class belong Clinch, Bays, and White Oak mountains, in Tennessee; and Taylors, Chattooga, Gaylor, Dirtseller, and Colvin mountains, in Georgia and Alabama. These are all narrow ridges, some of them of great length, extending parallel with the sides of the valley belt. Their crests are almost perfectly horizontal, making an even sky line like the plateau escarpment. These ridges are formed by a hard bed of Silurian sandstone of uniform thickness, which usually dips steeply to the east. Soft beds above and below have been worn down, leaving the hard one projecting as a ridge. The reason for this uniform altitude and these even crests will be given later.

The type of the second class of valley ridges is the Chilhowee Range, which lies along the western base of the more massive

Unakas. It includes Holston, Iron, English, Chilhowee, Starrs, and Beans mountains, in Tennessee; and Indian, Weisner, Choccolocco, and Terrapin mountains, in Alabama. These differ from the Clinch Mountain type in their greater altitude and less regular crests. They are due to massive beds of Cambrian quartzite, which is more resistant than the Silurian sandstone, and hence produces higher ridges; but, on the other hand, it is less uniform in thickness, so that the resulting ridges have less even crests.

The third class includes the very large number of low elevations that make up the minor irregularities of the surface,—broad rounded hills, sharp knobs, and narrow ridges, rising from 100 to 300 feet above the streams. Their form is dependent chiefly on the character of the material, the degree of relief, or the nearness to the main drainage lines. Seen from an elevation at the edge of the valley, these minor irregularities appear as a series of green billows, all reaching nearly the same level, above which rise, like islands, ridges of the Clinch and Chilhowee types: in other words, the elevations of this class reach a common plane, above which rise the larger ridges and highlands, and below which the present valleys of the streams are sunk. The significance of this plane will be pointed out later.

THE APPALACHIAN MOUNTAINS.—Having briefly described the topography of the adjoining physiographic districts, the main Appalachian Mountain belt will be next taken up. Some of its more prominent features have already been outlined, and will now be considered in greater detail.

The belt is not a unit dominated by a single range or group of mountains, but is complex, containing several elements of nearly equal importance. These are (1) the Blue Ridge, (2) the Eastern Monadnocks and Piedmont Valleys, (3) the Unaka Range, (4) the Central Mountain Groups and Intermontane Valleys.

The Blue Ridge.—The Blue Ridge, carrying the main divide between the Atlantic and Gulf drainage, is everywhere nearer the eastern than the western side of the mountain belt; and, neglecting a few groups of outlying mountains whose mass is insignificant compared with those west of the divide, the Blue Ridge may be regarded as forming the extreme eastern range of the Appalachian Mountains. It reaches its greatest height in Grandfather Mountain, with an altitude of 5,964 feet. Three other points reach above 5,000 feet; and a dozen or more, most of them in

North Carolina, above 4,000 feet. The gaps show a somewhat regular decrease in altitude on either side of the culminating point, from 4,000 feet in the vicinity of Grandfather Mountain, to 2,200 feet near the South Carolina line, and 2,700 at the Virginia line.

The most striking characteristic of the Blue Ridge is the great difference in slope on its opposite sides. The streams heading in the gaps upon the divide flow westward in broad, smoothly rounded, and drift-filled valleys for many miles before entering the narrow rock-cut gorges of their lower courses. Those flowing eastward, on the other hand, plunge immediately downward in a series of cascades, falling several thousand feet in a few miles. They have no valleys, only V-shaped gorges until they reach nearly to the level of the Piedmont Plain. This difference in slope is admirably shown on the Southern Railway from Asheville to Salisbury, N.C. From Asheville eastward, the road ascends the valley of the Swannanoa with an easy grade, making directly for the gap. Passing the divide, it descends upon the head waters of the Catawba by an intricate series of loops, winding back and forth upon the mountain side in such a way that at one point three tracks can be seen one above another, and a descent of 1,100 feet is accomplished between points only 3 miles apart in an air line. Reaching the level of the Catawba at an altitude of 1,400 feet, the road again follows a broad valley with easy grade down to the Piedmont Plain, which it reaches 50 miles to the eastward, at an elevation of 1,000 feet. Northward from the Virginia-North Carolina line — that is, in the Northern Appalachians — the Blue Ridge presents a comparatively smooth and regular face toward the east; and as far as the Roanoke River the divide is upon the extreme eastern edge of the mountain belt. Southward in North Carolina the divide is usually some distance from the edge of the belt, and many long spurs extend from the main ridge toward the south and southeast. They are separated by deep valleys, which often broaden into coves shut in by steep mountain walls. The most extensive of these spurs are at the head waters of the Yadkin and Catawba rivers, in the central part of western North Carolina. The eastward-flowing streams have cut back into the mountain belt, and, having the advantage of a more direct course to the sea, have encroached upon the territory of westward-flowing streams, — the New, Watauga, Nolichucky, and French Broad rivers, — and have robbed them

of portions of their drainage basins. Thus the Linville River, a northern tributary of the Catawba, has cut through the Blue Ridge proper, so that the latter forms a spur extending southward from Grandfather Mountain for 20 miles, the divide being on a less elevated ridge, parallel with it, and a few miles to the west.

The Blue Ridge, bearing the main divide, has a direct southwesterly course, with only minor deviations, across North Carolina. At the South Carolina line the divide turns abruptly to the northwest, making two broad loops which inclose the basins of the Chattooga and Tallulah rivers. South of the latter the divide returns to its former southwesterly course along the southeastern side of the Chattahoochee River. The Blue Ridge itself, though not followed by the main divide, continues southwestward across the corner of South Carolina as the Chattooga Ridge, and beyond the Chattooga River into Georgia as the Chattahoochee Ridge. The latter, at no point more than 1,600 feet in altitude, gradually merges into the Piedmont Plain before reaching Atlanta.

The Eastern Monadnocks and Piedmont Valleys.—In addition to the spurs from the Blue Ridge mentioned above, there are several groups of mountains along the extreme eastern border of the mountain belt, which have been more or less completely isolated by the erosion of eastward-flowing streams. The most important are the Brushy, South, and Saluda mountains. The first-named group lies between the Yadkin and Catawba rivers, extending for 50 miles nearly parallel with the Blue Ridge, and between 15 and 25 miles distant from the main divide. The highest points reach an altitude of 2,700 feet, while the gap between this group and the Blue Ridge is only 1,300.

South of the Catawba River are the South Mountains, which extend for 50 miles nearly east and west, their axis making a large angle with the Blue Ridge divide. A few points reach an altitude of 3,000 feet, or about 1,800 feet above the level of the Catawba and Broad river valleys.

The third group, the Saluda Mountains, also trend nearly east and west, their crest forming the boundary between North and South Carolina for about 20 miles. They are higher than the others described, reaching 3,100 feet, but are much less completely isolated, and may be considered as a spur from the Blue Ridge.

These three mountain groups are isolated from the Blue Ridge and from one another by the Yadkin, Catawba, and Broad river valleys. The latter are simply portions of the Piedmont Plain, with which they are continuous toward the east. They may be regarded as bays projecting westward from that plain between headlands formed by the mountain groups.

All of these groups are deeply dissected by erosion. Although once massive continuous ranges, they are now cut by deep transverse valleys into many short ridges and peaks. Their altitude decreases toward the east, and they give place in that direction to isolated knobs entirely surrounded by the Piedmont Plain.

It is evident that these outlying groups form an integral part of the Appalachian Mountain system. The main divide was formerly far to the east of its present position, but it is slowly migrating westward. The Atlantic drainage has the great advantage of a much shorter course to the sea, and hence steadily encroaches upon the territory of streams flowing westward. The Catawba, Yadkin, and Broad rivers have pushed the divide westward, and reduced the immediately adjacent conquered territory to the level of the Piedmont Plain, which until very recently was the base-level of erosion. The regions between these streams they have not yet had sufficient time to reduce completely, so that groups of mountains there remain which are the residuals of a former continuous highland: in other words, they are Monadnocks more or less typically developed.

In cases of recent capture, the stream valleys remain nearly at the elevation of the beheaded stream. Thus the upper portion of the Linville Valley has an altitude above 3,800 feet; and the stream, after flowing for 10 miles in a broad open valley, plunges into a narrow gorge with a fall of 1,000 feet in less than 3 miles. The upper valley of the Catawba, on the other hand, is below 1,500 feet, and only the smallest tributaries have rapid fall. In the latter case the conquered territory is thoroughly subjected; in the former the capture has been recent, and the reduction is not complete.

The Unaka Range.—The Unaka Range forms the northwestern member of the Southern Appalachian Mountains throughout the greater part of their extent. It does not form a continuous divide, as the Blue Ridge, but is cut through by numerous streams. From the Doe River northeastward the ranges fronting

upon the Appalachian Valley are long straight ridges with few lateral spurs; that is, they closely resemble the valley ridges already described. Although they are to be regarded as members of the mountain belt, since there is no lowland between them and the Blue Ridge, they differ materially from the Unakas. The latter may be considered as terminating between the Doe and Nolichucky rivers. Thence southwestward the range is fairly continuous for 200 miles to northern Georgia, although its different portions bear many local names.

As already stated, the highest point in the Blue Ridge, and the one reaching an altitude approaching 6,000 feet, is Grandfather Mountain. From this point, in which the Blue Ridge and the Unakas may be regarded as uniting, an irregular mountain range extends nearly due west 60 miles to Paint Rock on the French Broad River. This is the northern division of the Unakas. East of the Nolichucky it embraces Haw, Roan, and Unaka mountains; and between the Nolichucky and French Broad, the Bald, Big Butt, and Cow Bell mountains. Beyond the French Broad the range has greater unity, and reaches its typical development in the Great Smoky Mountains, which form a massive chain, continuous, except for Big Pigeon Gorge, for 75 miles to the Little Tennessee River. Beyond this the range is made up of smaller groups, separated by frequent river gorges. It includes the Sassafras, Unaka, Frog, and Cohutta mountains, terminating with the latter group in northern Georgia.

Compared with the Blue Ridge, the Unaka Range reaches a considerably greater average altitude, and contains most of the higher peaks in the Southern Appalachians. While the Blue Ridge contains only 4 points above 5,000 feet in altitude, the Unakas have 18 or more above 5,000; and of these, 8 are above 6,000. Not only have they greater altitude, but their slopes are steeper, and their outlines more angular and rugged. The Blue Ridge is generally steep only on the southeastern side, while the Unakas are equally steep on both sides, and slopes with a descent from crest to stream of 4,000 feet are not uncommon. Many high spurs leave the central chain, and between them are deep V-shaped ravines.

The Central Mountain Groups and Intermontane Valleys.—From any commanding point along the Unaka Range there may be seen stretching to the east and south a great sea of peaks, ridges, and domes. There is no dominating range, but most of

the peaks reach nearly the same altitude, and appear like the waves on a choppy sea, range after range growing less and less distinct, until their outlines are barely distinguishable from the blue sky at the horizon.

These are the mountain groups which occupy the central portion of the belt or basin between the outer ranges. The cultivated valleys are generally hidden from view, and except for an occasional clearing on the mountain sides, and the grassy "balds" on a few of the higher domes, the whole region appears to be covered with a forest mantle. Only rarely does a ledge of naked rock appear through the vegetation; so that the slopes are smoothed and softened, and the landscape lacks the rugged character of unforested mountain regions. The atmospheric effects also tend to produce the same result. The blue haze which is almost never absent from this region, and which is recognized in the names of both the Blue Ridge and the Great Smoky Mountains, softens the details of objects comparatively near at hand, and gives the effect of great distance to peaks but a few miles away. By reason of this atmospheric effect these mountains of only moderate altitude often afford more impressive views than heights and distances two or three times as great in the clear air of the West.

Some of these interior groups are more or less isolated, but most of them are in some degree connected with one or the other of the ranges which rim the basin. They generally have the form of short ranges from 5 to 20 miles in length, carrying a number of peaks a few hundred feet above the intervening gaps, and sending off long spurs which may themselves have peaks as high as the main ranges. There is no uniformity in their trend, although in most cases it is across the axis of the mountain belt rather than parallel with it. A very large number of the interior summits reach altitudes between 4,000 and 5,000 feet, and a few are over 6,000. The Black Mountains, a few miles north of Asheville, contain the highest peaks in the Appalachian Mountains. Mount Mitchell, with an altitude of 6,711 feet, is the highest point east of the Mississippi, being 425 feet higher than Mount Washington.

Between these groups, and forming a sort of platform above which they arise, are many broad valleys, commonest toward the heads of the streams, and hence in the southeastern side of the basin; that is, along the northwestern base of the Blue Ridge.

Only the smaller streams are still flowing at the level of these valleys. Followed downstream toward the northwest, the broad valleys are found to be more and more deeply cut, until finally all trace of them is lost, and the streams are found in deep narrow gorges. These gorges in which the streams in their lower courses flow are being cut backward into the valleys at their head waters: hence the broad valleys were evidently formed under conditions different from those prevailing at the present time. They must have been formed near sea level, when their streams had cut down to base-level, and were widening their channels by lateral corrasion. The presence of these high valleys is the best possible evidence that the altitude of the region in which they are found has been increased by elevation in comparatively recent times.

The characteristics of these intermontane valleys are admirably displayed in the vicinity of Asheville, N.C. Seen from an altitude of about 2,200 feet, the region appears as a broad level plain, stretching in all directions to the base of the surrounding mountains, which rise from it with abrupt slopes. The same plain with slight rise extends far up the Swannanoa and French Broad rivers, and up the smaller streams among the mountain spurs. At Asheville the river has cut a channel a little more than 200 feet deep within this plain, and this channel increases rapidly in depth toward the northwest, in which direction the river and its tributary streams have deeply dissected the plain. Its remnants, however, still reach a common level, so that it can be easily reconstructed. Eastward on the Swannanoa, and southward on the French Broad, the plain is less and less dissected, and toward the head waters of these streams the broad valleys are almost perfectly preserved. These intermontane valleys are found on all the northwestward-flowing streams of the mountain belt; but they increase in extent, and at the same time decrease in altitude, toward the southwest. On the French Broad the altitude of the valley is about 2,200 feet; on the Little Tennessee, 2,000; on the upper Hiwassee, 1,800; on the Ocoee, 1,700; on the Coosawattee, 1,500; on the Etowah, 1,100; and on the Tallapoosa, 1,000. They appear on the first three of the above-named streams as described on the French Broad,—level arenas, walled in upon all sides by the encircling mountains, with a narrow gateway leading westward through the Unakas to the Great Valley. Southward from the Hiwassee, the adjacent valleys

merge with low divides, and the mountain groups are more completely isolated. Still farther south, on the Etowah and Tallapoosa, the valleys are so broadly developed that the divides separating adjacent basins are scarcely perceptible, and the only mountains remaining are isolated, island-like Monadnocks. Excellent examples of the latter are seen in Kennesaw and Lost mountains, in northern Georgia. From a distance of a few miles they appear as smooth oval domes, rising with symmetrical slopes above a level plain. This plain is slightly etched by the present stream channels, which are from 50 to 150 feet in depth, but on the horizon it makes a perfectly even sky line. It extends entirely across the mountain belt from the Great Valley to the Piedmont Plain, southwest from the vicinity of Marietta to the Alabama line, interrupted only by a few low Monadnocks. In Alabama it is less perfectly developed, and the interrupted Appalachian Mountains reappear in the Talladega Range. The latter forms a narrow mountain group 50 miles in length, consisting of a high central ridge bordered by low hills. It should properly be considered the southern member of the Unakas, although separated from the main range by an interval of nearly 100 miles.

Dependence of Surface Forms on the Character of the Rocks in the Mountain Belt.—It was shown in a preceding part of this monograph that the physiography of the Cumberland Plateau and of the Great Appalachian Valley was most intimately connected with the character and attitude of the rocks underlying those regions. It was there shown that horizontal beds of varying hardness are carved by streams into plateaus; and that the same beds, when tilted, produce long, narrow ridges. In like manner the form of the surface in the mountain belt is in large measure dependent on the character of the underlying rocks, although its greater altitude is due in part to recent uplift.

In their behavior toward the agents of erosion, the rocks of this region differ from those toward the west chiefly in being more homogeneous. They consist in part of crystalline rocks which have solidified from a molten state, as granite and diorite, with crystalline schists derived from them; and in part of slates and conglomerates, sedimentary rocks, which have been more or less altered by heat and pressure. Excepting a few beds of marble, limestones are entirely wanting. The original differ-

ences in hardness between such sedimentary beds as shale and conglomerate have been nearly obliterated by subsequent changes which they have undergone, so that they present nearly the same degree of resistance to the agents of erosion. For this reason the mountain ranges do not generally conform in trend to the strike of the rocks; while there is a very uniform northeast strike within the mountain belt, the crests of the interior ranges in particular are extremely irregular, and the long spurs are quite as apt to cut across the strike as to follow it.

Some differences in the underlying rocks, however, find expression in slight differences in the topographic forms. Thus the southeastern portion of the mountain belt is occupied almost exclusively by crystalline rocks, and these generally give rise to broad and massive domes with smooth contours. Such forms characterize the Blue Ridge and adjacent mountain groups. The northwestern portion of the belt, on the other hand, is occupied chiefly by metamorphic rocks. These yield less readily to disintegration than the wholly crystalline rocks: hence the greater altitude of the Unaka Range, and the prevalence there of sharp peaks rather than of rounded domes.

DRAINAGE OF THE SOUTHERN APPALACHIANS.

The streams of the Southern Appalachians have already been frequently mentioned in the foregoing physiographic description of the region, but the drainage requires a few words of further explanation.

The waters falling upon various parts of the region find their way either eastward to the Atlantic, southward directly to the Gulf of Mexico, or to the Mississippi and thence to the Gulf. The divide between the Atlantic and Gulf drainage follows the crest of the Blue Ridge, as already described, from the Roanoke southwestward. The eastward-flowing streams are pressing this divide gradually westward by the capture of territory from less favorably situated streams west of the divide. Cases of recent capture are seen at the head of the Linden and Tallulah rivers, the falls on those streams showing that the newly acquired territory has not yet been in their possession sufficiently long to be completely subdued. Northwest of the divide the streams flow

at first in the high valleys, many of which were evidently formed by larger streams than those now occupying them. Leaving the Blue Ridge, with its gentle slopes and low gaps, they flow northwestward in deepening channels, directly toward the higher and more rugged Unakas, which they cut through in narrow gorges. Emerging upon the Appalachian Valley, those south of New River are intercepted by trunk streams, and led off toward the southwest. From New River to the Georgia line the trunk stream is the Tennessee, which leaves its southeastward course and at the same time the broad Appalachian Valley by an abrupt bend at Chattanooga, traversing the Cumberland Plateau in a narrow gorge evidently much younger than other portions of its valley. Southward from the Georgia line the trunk stream is the Coosa, which flows directly to the Gulf, following the axis of the Great Valley.

The divide between the Tennessee system and streams flowing directly to the Gulf leaves the Blue Ridge in northern Georgia, and follows an irregular line toward the west, crossing successively the mountain belt, the Great Valley, and the plateaus. It is peculiar in not following the crest of a ridge for any distance, but in cutting across ridges and valleys marked in many places by a barely perceptible rise of the land. There is evidence that this divide, like the gorge of the Tennessee through the plateau, is extremely young; that until comparatively recent times all the waters flowing west from the Blue Ridge found their way directly to the Gulf across the present Tennessee-Coosa divide.

The stream courses within the valley belt show a close adjustment to the structure of the region. In general they are located upon belts of soft rocks; and when they leave these, they always cross intervening hard beds by the most direct course at right angles to the strike. They more often occupy the axes of anticlines than of synclines, so that they must have migrated to their present locations by the process of stream adjustment outlined by Mr. Willis in Monograph No. 6.

PHYSIOGRAPHIC DEVELOPMENT OF THE SOUTHERN APPALACHIANS.

Having before us the main physiographic features of the Southern Appalachian region, we are prepared to follow an out-

line of the history of its development. Its earlier history, while the region was in part, at least, covered by the sea, is read in the sedimentary rocks; while the later chapters, covering the periods during which it has been dry land, are inscribed in the forms of the land surface and the relations of its streams.

Studying the rocks of the three western divisions of the province, we know that the sediments of which they were composed were derived largely from land lying toward the southeast, probably in the region now occupied by the Piedmont Plain and beyond. In very early times the sea may have covered what is now the Blue Ridge; but, if so, the shore line was early pushed toward the northwest, uncovering to erosion the present mountain belt, which furnished much of the material for the later sedimentary rocks. For a long time the sea margin was near the northwestern side of the mountain belt, oscillating within narrow limits, but gradually migrating westward. Something can be learned, from the sedimentary rocks thus laid down, of the old land area from which their materials were derived. Thus conglomerates indicate steep slopes and rapid streams, while limestones point to the opposite extreme,—a land with low relief and sluggish streams, able to supply but little fragmental material to the adjoining sea. At least two great cycles of erosion are thus recorded in which the surface of the old continent was worn down from a considerable altitude nearly to base-level.

Shortly after the close of the Carboniferous period the entire Southern Appalachian Province was finally lifted above sea level, and its subsequent history is recorded chiefly in land forms. At the same time that the region was elevated, the strata in a long narrow belt adjacent to the old shore line were intensely folded. The streams flowing from the old land into the interior sea before the emergence doubtless continued in the same direction, extending their lower courses across the newly added land as successive belts emerged. Since the process of folding was exceedingly slow, they may have held their original courses for a long time in spite of the folds rising across their path. These folds, however, although not directly able to turn the rivers aside, brought bands of soft rocks above base-level, and so were able indirectly to accomplish that result. Streams flowing southward parallel with the folds were located entirely upon soft rocks, and so were able to deepen their channels more

rapidly than those flowing westward across many hard beds: hence the streams parallel with the folds encroached upon the territory of the transverse streams, and successively captured them, and led them by southwestward courses directly to the Gulf. When once fairly started, the conquest proceeded rapidly toward the northeast; but, before it had reached New River, the latter had been able to sink its own channel so deeply that the Holston could not cut through its banks and divert it. It intrenched itself successfully against the encroachments of its marauding neighbor. New River therefore continues north westward from its source on the Blue Ridge, across the mountain belt, the Great Valley, and the Cumberland Plateau. It is the only stream in the entire Appalachian Province which retains throughout its entire length approximately its original position.

Following this uplift was a long period during which the region was subjected to the physiographic processes constituting gradation. These have been described in preceding monographs. Probably base-leveling was several times carried nearly to completion during this period; but the peneplains thus formed were destroyed by subsequent erosion, and no record of them remains. Finally, toward the close of Cretaceous time, the whole province was reduced to a nearly featureless plain, relieved only by a few groups of Monadnocks where the highest mountains now stand.

After the process of base-leveling was nearly completed—that is, toward the close of the Cretaceous—the region was again lifted, but unequally, so that at the same time its surface was warped. The streams had become sluggish, but the effect of the uplift was to stimulate them to renewed activity. They began at once to lower their channels in the old peneplain, and, when they had reached the new base-level, to form a new peneplain by lateral corrasion. This process went on most rapidly on areas underlain by easily erodible rocks; so that the new peneplain was extensively developed on the limestones of the valley belt, while the streams still flowed approximately at the old level on the hard sandstones of the plateau and the slates of the mountain belt. It is from these remnants preserved upon areas of hard rocks that we are able to reconstruct the older peneplain. The largest remnants are seen in the smooth, even summits of the Cumberland Plateau. It is also preserved in the

even crests of the valley ridges, and the high valleys within the mountain belt.

The formation of the second peneplain was well advanced over areas of soft rocks, when the region was again subjected to a series of vertical oscillations, the final result of which was elevation accompanied by warping. As before, the effect of the elevation was to stimulate the streams so that they began cutting upon the last-formed peneplain,—a process in which they are still engaged.

During the last series of oscillations mentioned above, some important changes were produced in the drainage. Previous to this the waters of the valley belt from New River southwestward had collected into a single trunk stream, which flowed across the present divide directly to the Gulf by the present course of the Coosa River. A peculiar set of conditions for a time gave sufficient advantage to a westward-flowing stream to enable it to cut through the plateau, and divert the trunk stream westward to the present course of the Tennessee.

RELATION OF RECENT UPLIFT AND PRESENT ALTITUDE.

It was shown in describing the Appalachian Mountains that from the culminating point in North Carolina the average altitude of the belt decreases southwestward; that the bounding ranges, the Blue Ridge and Unakas, as well as the interior mountain groups, become less massive and more deeply cut by transverse drainage channels; and that the intermontane valleys, which in the northern part of the belt are walled in by mountains upon all sides, occupy an increasing proportion of the area, until in Georgia they form a level plateau stretching entirely across the belt, and interrupted only by a few isolated Monadnocks. The cause of this gradual decrease in altitude toward the southwest can now be understood. It is not due to the presence of more easily erodible rocks in the southern than in the northern portion of the belt; for they are essentially the same kinds, and, in their unweathered condition, offer the same degree of resistance to agents of gradation. The cause is rather in the different amounts of uplift which the two regions have suffered in recent geologic periods. It was stated above that the Southern Appalachians had been several times more or less completely base-leveled, and that each base-leveling period was followed by

an uplift which stimulated the streams to renewed activity upon the peneplain. It is evident that the depth of the gorges cut by the rejuvenated streams would depend on the amount of the uplift; and hence the height of the mountains, which are simply remnants of the deeply dissected peneplain, would also depend on the amount of uplift. In regions where the uplift was great, the intervening portions of the peneplain would long remain as high mountain masses; and, on the other hand, where the uplift was slight, the streams would quickly cut down to the new base-level, and begin the task of removing the intervening highlands: hence moderate uplift would not only give rise to low mountains, but would favor the formation of isolated Monadnocks.

Again, during the later stages of the base-leveling process, the rocks of a region became deeply weathered; so that, when the streams are accelerated by uplift, erosion is at first much more rapid in the soft surface rock than it is when the fresh rock beneath is reached: hence, if the uplift in any region is but one or two hundred feet, the streams may encounter only soft material in forming the new peneplain; whereas, if the uplift is one or two thousand feet, far the greater part of their work will be in hard, unweathered material. Now, it was shown that in the Southern Appalachians two peneplains are sufficiently well preserved so that we are able to reconstruct their surfaces, and determine the amount of uplift which they have subsequently undergone. In both of these cases the uplift terminating one base-leveling cycle and inaugurating another has been unequal, greatest near the culminating point of the Appalachians, and gradually decreasing southwestward. Moreover, it seems probable that the elevation of previous peneplains in the same region has been of the same character, greatest toward the north, and decreasing southwestward: hence the present decrease in altitude of the Southern Appalachian Mountains toward the southwest, and the corresponding increase in the proportion of area occupied by base-leveled valleys, are traced directly to differential uplift in recent geologic periods.

INFLUENCE OF PHYSIOGRAPHY ON SOCIAL AND INDUSTRIAL DEVELOPMENT.

The physiography of any region determines to a large extent the character of the social and industrial development of its

people. It also has an influence somewhat less direct on their moral and intellectual development. Some of the more obvious ways in which the physiography of the Southern Appalachians has affected the people and institutions will be pointed out.

The first settlement of the region was along the Atlantic coast and up the navigable rivers to the "fall line." Here the streams leave their rocky channels on the Piedmont, by a series of rapids and falls, for deep channels across the Coastal Plain. At the head of navigation on the rivers, trading posts were at first established, which have since developed into thriving cities. From these outposts pioneers pushed farther inland over the whole Piedmont Plain, and up to the heads of the fertile valleys among the eastern spurs of the Appalachian Mountains. For a time the Blue Ridge checked further advance westward; but this was soon crossed, and the intermontane valleys upon its western side occupied. Beyond these were the rugged Unakas, which long presented an insurmountable obstacle to further progress. To the natural difficulties of travel were added the dangers from the warlike Cherokee Indians, who found the dark, narrow ravines well suited for their mode of warfare.

Hunters brought back to the eastern settlements alluring tales of rich valley lands beyond the mountains, and even before the Revolution a few hardy pioneers had settled in the Appalachian Valley. Unable to pass the Unaka Range, two possible routes to the region were left,—one by way of the James or Roanoke gaps, through the Blue Ridge, and thence southwestward down the valley; and the other through northern Georgia, around the southern end of the mountain ranges. The latter route was little used on account of the hostile Creeks and Cherokees, and nearly the entire immigration of the western portion of the Appalachians came in by the northern route. In the early decades of the century the region was rapidly settled, chiefly from the Carolinas, Virginia, and Georgia. The Cherokees were gradually crowded within narrower limits as their rich lands were first coveted and then appropriated by the whites. Finally, between 1830 and 1840, their hunting grounds were purchased by the Federal Government, and most of the tribe was removed to the Indian Territory. A few families of the tribe refused to leave their old home, and could not be dislodged from the remote mountain valleys to which they had retreated. Their descendants still occupy a small reservation in west-

ern North Carolina, only partially civilized by contact with their neighbors.

The Appalachian Mountains, and in some measure also the Cumberland Plateaus, thus acted as barriers to the advance of settlement; so that the tide of immigration was for a time checked, and turned from the more direct course to one which offered less resistance. With the advent of railroads the same lines of least resistance were followed which had directed the tide of immigration. The products of the interior sought an outlet to the east; but from the Roanoke southward for 350 miles the Appalachian Mountains offered a serious obstacle, and not until after 1880 was this portion of the mountain belt crossed by any railroad. Past the southern end of the mountains, through northern Georgia, there was a natural outlet for the interior across the base-leveled plain already described; and this was utilized for one of the earliest roads built in the South.

Few obstacles were met in building roads on the Piedmont Plain, and comparatively few in the Appalachian Valley. Where these natural routes are intersected by the transverse route across the mountain belt, there thriving cities have grown up. Atlanta, the "Gate City," stands at the portal of the Southern Appalachians, on the only natural route from the Tennessee basin to the southeast.

For a long distance on either side of Chattanooga, both toward the north and south, the Cumberland Plateaus present high, steep escarpments toward the valley, offering serious, if not insuperable, obstacles to east and west roads. Toward the west, however, the plateaus are deeply cut by transverse streams, along which roads have been built with comparative ease. Thus Chattanooga is also a "gate city," standing at the portal through which must pass all traffic between the great Interior Lowlands and the Southern Appalachian Valley.

Ease of communication is so important a factor in modern social development, that regions abundantly supplied with railroads advance far beyond those still dependent on less rapid transit: hence there are greater differences between the social conditions in the valleys and among the mountains than could possibly exist when the two regions were more nearly on an equality in this respect. The people remote from railroads are relatively much more isolated than they were when the only means of travel between the different parts of the country were

on horseback or by stage. Many of the people in this region have been scarcely at all affected by the modern industrial and social revolutions which have been going on around them. In some of the more remote mountain valleys the mode of life does not differ essentially from that which prevailed throughout most of the country during colonial times. Practically everything consumed in the household is of domestic manufacture, and the people have few wants which must be supplied from the outside world. In these isolated communities are found the direct descendants of early Virginia and Carolina immigrants, with scarcely a trace of foreign admixture. They are perhaps the purest stock in the United States. Curious archaic customs and forms of speech are preserved among them which have entirely disappeared elsewhere.

There is still another way in which physiography has affected the people, scarcely less important than by controlling the ease of intercommunication between communities. Until within a few years the people of the Southern Appalachian region have been engaged almost exclusively in agricultural pursuits. Differences in soil and climate have determined the crops which could be raised with profit, and hence mode of cultivation and social conditions. Only the lowlands on either side of the Appalachians and the southern portion of the Great Valley were suited to the cultivation of cotton: hence in the highlands, where diversified crops and small farms were the rule, the institution of slavery did not gain a firm footing, as it did in the cotton-raising districts. Some counties of North Carolina even now do not contain a single negro. These different social conditions which prevailed for two generations prior to the Civil War, and which were traceable directly to physiographic causes, have left effects upon the people which will require many years to eradicate.

The industrial revolution now in progress in the South, by which it is being converted from a purely agricultural to a manufacturing region, is due in large part to physiographic causes. Within a belt embracing the eastern portion of the plateau and the western edge of the valley, conditions are extremely favorable for the cheap production of iron. Fuel from the plateaus, and ore and flux from the valley, are brought together with a minimum of expense; and manufacturing towns are springing up within this belt from Virginia to central Alabama.

Cheap power is even more important than abundant raw materials in building up manufactures; and, with modern improved methods for the transmission of power by electricity, water is to some extent replacing steam. The Southern Appalachians are rich in water power. The streams which flow westward from the mountain belt have large catchment basins in the high intermontane valleys. In their courses to the Appalachian Valley are many rapids, particularly where they break through the Unaka Range; and much of the power now going to waste in these rapids will undoubtedly be utilized before many decades. The manufacturing communities resulting from this utilization will be directly due to recent uplift of the Appalachian Mountain belt.

It is thus seen that the physiography of the Southern Appalachians determined lines of early settlement, and directed the subsequent tide of immigration by which the region was peopled; that it determined the lines of traffic and travel, the location of cities, and the relative development of different communities; that it determined the occupations and thereby the social conditions in different portions of the region; and, finally, that it must in future exercise an important influence upon its industrial development and the material welfare of its people.

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